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Protein Recovery From Beef Packing Effluent

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PROTEIN RECOVERY FROM BEEF PACKING EFFLUENT

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FOREWORD

When energy and material resources are extracted, processed, converted, and used, the related pollutional impacts on our environment and even on our health often require that new and increasingly more efficient pollution control methods be used. The Industrial Environmental Research Laboratory-Cincinnati (IERL-Ci) assist in developing and demonstrating new and improved methodologies that will meet these needs both efficiently and economically.

A physiochemical wastewater treatment process that recovers protein from beef packing and similar effluents was investigated on a full scale basis. The effluent from the beef packing plant contained an average of 4,600 mg/l COD and 2,500 mg/l of suspended solids. This process was found to be capable of removing over 80% of the oxygen demand and suspended solids, and 94% of the fat, oil, and grease.

Total operating and capital costs were $3 per 1,000 gallons treated if no credit is taken for the protein recovered and sold. About 2 pounds of protein per head are recovered and the average quantity of wastewater treated in this plant was 276 gallons per head. Consequently, the average cost of treatment was 83¢ per head, so that the protein recovered would have to sell for about 42¢ per pound of protein in order to recover all costs.

The discharge of BOD from this beef packing plant was reduced to less than 3 pounds per head. The wastewater treatment process can be used as a pretreatment process for beef packing effluent prior to discharge to a conventional sewage treatment plant.

For further information regarding this report, contact Ken Dostal, Food and Wood Products Branch, Industrial Environmental Research Laboratory - Cincinnati, Ohio 45268.

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ABSTRACT

The effluent wastewater from the Sterling Colorado beef packing plant contained an average of 4,600 mg/l COD and 2,500 mg/l of suspended solids. A physiochemical wastwater treatment process that recovers protein from this effluent was investigated on a full scale basis. This process uses H_2SO_4 for pH reduction, Calcium lignosulfonate for protein precipitation, and $Ca(OH)_2$ for both effluent and sludge neutralization, and is marketed by the Alwatech Corporation.

The Alwatech process is capable of removing over 80% of the oxygen demand (COD and BOD) and suspended solids, and 94% of the fat, oil, and grease from beef packing effluent. The optimum Calcium lignosulfonate dose is about 5% of the influent COD concentration and the optimum pH is near 2.

Total observed operating costs were 47¢ per head or $1.68 per 1,000 gallons of wastewater treated. It is believed that operating costs can be reduced to about 40¢ per head by using less Calcium lignosulfonate than was used during the course of this project. Calcium lignofulfonate accounted for 39% of the total operating costs followed by 25% for labor, 25% for H_2SO_4 and $Ca(OH)_2$, 9% for energy, and 2% for repairs.

Capital costs (including real estate taxes, interest, recovery of principal, and insurance) were an additional $1.32 per thousand gallons treated, so the total cost was $3 per 1,000 gallons treated. About 2 pounds of protein are recovered per head, so this recovered protein would have to sell for about 42¢ per pound of protein in order to recover all costs.

While the sludge centrifuge efficiency was 94% for water, it was only 52% for total solids, 66% for protein, 21% for oil and grease, and 76% for other solids. Recirculation of the centrifuge reject solution back to the plant influent increases the influent COD 32%, the influent suspended solids 29%, and the influent grease and oil 36 to 52%.

The discharge of BOD from this beef packing plant has been reduced to less than 3 pounds per head. For every pound of BOD entering the Alwatech plant, 0.77 pounds of product was recovered with a composition of 38% protein, 11% grease and oil, 27% inorganic solids, and 24% other solids (dry weight basis).

The Alwatech process can be used as a pretreatment process for beef packing effluent prior to discharge to a conventional sewage treatment plant.

This report was submitted in fulfillment of Grant No. S 804505 by Sterling Colorado Beef Company under the partial sponsorship of the U.S. Environmental Protection Agency. This report covers the period from November 1, 1977, to July 31, 1979, and work was completed as of October 31, 1980.

CONTENTS

Page

FOREWORD iii
ABSTRACT iv
FIGURES x
TABLES xi
ABBREVIATIONS AND SYMBOLS.................................. xiii
ACKNOWLEDGMENT xvi

1. INTRODUCTION 1
    Summary 1
    Unit Waste Production.............................. 2
    Brief Description of the Process Evaluated 2
    Scope of This Project.............................. 3
2. CONCLUSIONS 4
    Summary 4
    Monthly Average Effluent Concentrations 5
    Ammonia and Organic Nitrogen 5
    Phosphate and Fecal Coliforms 6
    Solids 6
    Material Balances of Pollutants................ 6
    Filter Belts 6
    Economics 6
3. RECOMMENDATIONS 8
4. LITERATURE SURVEY 10
    Anaerobic Lagoons 11
    Combination Biological, Chemical,and Physical Treatment System 13
    Dissolved Air Flotation (DAF).................. 14
    Electrocoagulation.. 16
    Protein Recovery by Ion Exchange 20
    Protein Recovery Using Chitosan................ 21
    Protein Recovery Using Lignosulfonate........... 25
    Historical Development of the Alwatech Process.. 30
    Theory of Precipitation with Lignosulfonate 31
    The Use of Recovered Protein Concentrate as Animal Feed 32
    Safety of LS Precipitated Proteins as Animal Feed Supplements 36
    Protein Quality and Feeding Trials 37
    General Description of the Alwatech Process 39
    Alwatech Process Pilot Plant Results 40
5. DESCRIPTION OF THE STERLING COLORADO BEEF COMPANY MEAT PACKING OPERATION.................................. 43

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Cattle Pens.................................... 43
Slaughtering Department........................ 43
Blood Processing............................... 45
Hide Removal and Processing.................... 46
Viscera Handling............................... 46
Paunch Manure and Tripe........................ 46
Inedible Rendering............................. 47
Edible Tallow.................................. 47
Water Conservation............................. 47
Water Recycle and Blowdown Water............... 47
Description of the Alwatech Process Installed at the Sterling Colorado Beef Company Plant............. 47

6. OBSERVED DATA SUMMARIES........................ 56
Maintenance.................................... 56
Repairs.. 56
Operating Log Summary.......................... 56
Weekly Plant Operating Summary................. 63
Water Use...................................... 68
Rendering Condenser Wastewater Quality......... 68
BOD Concentration Versus Time.................. 68
Wastewater Treatment Plant Results............. 71
Wastewater Discharged to the Sewage Treatment Plant.. 94
Bottom Sludge Production....................... 98
Sludge Composition............................. 98
Dried Sludge Production........................ 106
Developments During this Project............... 108

7. ANALYSIS OF OBSERVED DATA...................... 110
Organic Nitrogen Removal Efficiency............ 110
Centrifuge Efficiency.......................... 112
Optimum pH and Lignosulfonate Concentration.... 122
% COD Removal and Other Plant Performance Parameters.................................... 124
Sulfuric Acid and Calcium Hydroxide Requirements.. 125
Minimum Cost pH................................ 126
Monthly Average Effluent Concentrations........ 131

8. PROTEIN RECOVERY ECONOMICS..................... 136
Total Operating Costs.......................... 136
Capital Costs.................................. 142

9. COMPARISON OF THE ALWATECH PROCESS RESULTS WITH OTHER PROTEIN RECOVERY PROCESSES............................ 145

10. MATERIAL BALANCES OF POLLUTANTS AROUND THE ALWATECH PROCESS.. 146
COD.. 148
Suspended Solids............................... 149
Grease and Oil................................. 149
% Removal of COD, Suspended Solids, and Grease and Oil.. 150

11. REFERENCES.................................... 156

12. BIBLIOGRAPHY.. 156
13. APPENDIX-WASTEWATER AND SLUDGE EXAMINATION TECHNIQUES USED.. 159

FIGURES

Number		Page
1	Organic Nitrogen Removal Efficiency at Optimum pH for a Chitosan Dose of Zero	23
2	Typical Segment of Sulfonated Lignin Molecule	28
3	Flow Chart for the Sterling Colorado Beef Company Packinghouse	44
4	Sterling Colorado Beef Company Alwatech Plant Layout	49
5	East Side of Protein Recovery Plant Building	48
6	Sterling Colorado Beef Company Alwatech Process Flow Diagram	51
7	Flotation Tanks I and II	52
8	Air Pressurization Tanks and Associated Equipment	53
9	$Ca(OH)_2$ Mixing and Effluent Neutralization Tanks	54
10	Process Control Panel	55
11	Average Sludge Composition	107
12	Comparison of Calculated and Observed Organic Nitrogen Removal	111
13	Sludge Handling Products	113
14	Quantities per 100,000 pounds of Wet Sludge	119
15	Solids Composition	121
16	R versus pH	128
17	Chemical Cost as a Function of pH Used and Influent COD Concentration	130
18	Frequency Distribution of September, 1978, Grease and Oil Effluent Concentrations	133
19	Effluent Suspended Solids Concentration Frequency Distribution	134
20	Effect of R on % COD Removal	140
21	Optimum R	143

TABLES

Number Page

1 Comparison of Beef Packing and Domestic Wastewaters...... 1
2 Unit Waste Production.................................. 2
3 Operating Parameters................................... 11
4 Anaerobic Lagoon Treatment Efficiencies................. 12
5 Treatment Efficiency and Byproduct Recovery............. 14
6 Performance of DAF Units Treating Beef Packinghouse Wastes.. 15
7 DAF Treatment of Hog Slaughterhouse and Poultry Processing Wastes... 15
8 DAF Treatment of Shrimp Canning Wastes.................. 16
9 Packinghouse Wastewater Treatment at pH 4.5............. 17
10 Meat Processing Wastewater Treatment at pH 4.75.......... 18
11 Comparison of 3 Types of Electrocoagulation.............. 19
12 Influent Concentrations and % Removal Using Chitosan and Activated Carbon.. 24
13 Costs Associated with the Treatment Results Shown in Table 12 for 0 g/l Activated Carbon...................... 25
14 Properties of Various Lignosulfonates................... 30
15 Effect of pH on Protein Precipitation by LS............. 32
16 Comparison of Alwatech Recovered Protein with Commercial Herring Meal.. 34
17 Material Recovered from a Pork Slaughtering Plant........ 34
18 Rendered Alwatech Sludge from an English Poultry Packing Plant.. 35
19 Amino Acid Composition of Crude Protein................. 35
20 Effect of LS Protein Supplement upon Chick Growth........ 37
21 Results of Chick Feeding Trials......................... 38
22 Comparison of Pilot Plant and Full Scale Plant Performance... 41
23 Maintenance... 57
24 Annual Repair Costs..................................... 59
25 Operating Log Summary................................... 61
26 Alwatech A/S Performance Guarantee for the Sterling Colorado Beef Company Wastewater Treatment Plant......... 62
27 Actual Alwatech A/S Performance for the Second 2 Week Trial Period.. 63
28 Alwatech A/S Performance for the Third 2 Week Trial Period.. 63
29 Weekly Plant Operating Summary.......................... 65
30 Unit Water Use.. 69
31 Analyses of Water from the Rendering Condensers.......... 70

Number Page

32 Wastewater Treatment Plant Results........................ 72
33 Influent and Effluent Solids Concentrations and % Removal........................ 94
34 Analyses of Water Discharged to the Sewage Treatment Plant........................ 95
35 Concentrations and Contributions to the Wastewater Discharged to the Sewage Treatment Plant........................ 97
36 Concentrations and Contributions to the Wastewater Discharged to the Sewage Treatment Plant in the Absence of Wastewater Treatment........................ 98
37 Bottom Sludge Production........................ 99
38 Sludge Composition........................ 100
39 Average Sludge Composition........................ 106
40 Dried Sludge Production........................ 108
41 Average Protein Concentration in the Dried Sludge........ 109
42 Sludge Composition Used........................ 114
43 Observed Quantities of Wet, Dewatered, and Dried Sludge.. 115
44 Solids Production........................ 116
45 Protein, Grease, and Oil in Sludge........................ 117
46 Average Sludge Quantities........................ 118
47 Centrifuge Efficiencies........................ 120
48 Sludge Drier Efficiencies........................ 121
49 Ultimate Fate of Wet Sludge........................ 122
50 Data for Determination of Optimum pH........................ 123
51 % COD Removal and Other Plant Performance Parameters..... 125
52 R versus pH........................ 127
53 Monthly Average Effluent Concentrations........................ 132
54 Total Operating Costs........................ 138
55 Effect of R on % COD Removal........................ 139
56 The 20 Lowest Values of R Used........................ 141
57 Data Required for Material Balances........................ 147
58 Material Balance Sludge Production........................ 148
59 Material Balance Liquid Quantities........................ 148
60 COD Material Balance........................ 149
61 Suspended Solids Material Balance........................ 149
62 Grease and Oil Material Balance........................ 150
63 Wastewater and Sludge Examination Techniques Used........ 160
64 Solids States Relationships........................ 161

LIST OF ABBREVIATIONS AND SYMBOLS

CAPITALIZED ABBREVIATIONS

BAT	-- best available technology economically achievable
BOD	-- biochemical oxygen demand
BOD_5	-- 5 day BOD
BPT	-- best practical control technology currently available
C	-- centrifuged
COD	-- chemical oxygen demand
D	-- dried
DO	-- dissolved oxygen
FOG	-- fat, oil, and grease
JTU	-- Jackson turbidity units
LS	-- lignosulfonate
LWK	-- live weight kill
N	-- neutralized
R	-- reject solution from centrifuge
SD	-- standard deviation
V	-- vapor
W	-- wet
#	-- number
%	-- percent

UNIT ABBREVIATIONS

Btu*	-- British thermal unit (1 kwhr=3,412 Btu)
°C	-- degrees Centrigrade
cfm	-- cubic feet per minute
cm	-- centimeter
D	-- day
°F	-- degrees Fahrenheit (°F=32+1.8°C)
ft.	-- foot (1 ft=30.48 cm)
g	-- gram
gal	-- gallon (1 gal=3.785 liters)
gpd	-- gallons per day
gpm	-- gallons per minute
hp	-- horsepower (1 hp=0.7457 kilowatts)

*English units are used in order to save prodigious quantities of time and money. In addition, the report would have been useless to its intended audience if metric units had been used. With the exception of laboratory measurements, all observations were made in English units. Conversions to metric units are given for each basic English unit.

List of Abbreviations and Symbols (continued)

UNIT

hr	-- hour
kwhr	-- kilowatt-hour
l	-- liter
lb	-- pound (1 lb=454 grams)
M	-- month
me	-- milliequivalent
mg	-- milligram
mgad	-- $\frac{\text{million gallons}}{\text{(acre) (day)}}$, (1 acre=43,560 ft^2)
mgd	-- million gallons daily
min	-- minute
ml	-- milliliter
mm	-- millimeter
sec	-- second
y	-- year
u mho	-- micromho
¢	-- cent
$	-- dollar

ATOMS

Al	-- aluminum
C	-- carbon
Ca	-- calcium
H	-- hydrogen
N	-- nitrogen
O	-- oxygen
P	-- phosphorous
S	-- sulphur

ANIONS

NO_3^-	-- nitrate
NO_2^-	-- nitrite
$PO_4^{\equiv}$	-- phosphate

COMPOUNDS

$Al_2(SO_4)_3$	-- aluminum sulfate
NH_3	-- ammonia
$CaCO_3$	-- calcium carbonate
$Ca(OH)_2$	-- calcium hydroxide
CO_2	-- carbon dioxide
CH_4	-- methane
H_2SO_4	-- sulfuric acid

List of Abbreviations and Symbols (continued)

MATHEMATICAL SYMBOLS AND UNITS

c -- capital costs, $
D -- dose, mg/l
F -- organic nitrogen removal efficiency, %
i -- interest rate, decimal per year
I -- annual cost of insurance, decimal per year
p -- property taxation rate, decimal per year
Q -- capacity (16 hours per day), gpd
R -- $\frac{\text{mg/l Ca LS}}{\text{mg/l COD in influent}}$, dimensionless
t -- life of the system, years
T -- temperature, °C or °F
x -- conversion constant

ACKNOWLEDGMENTS

The Sterling Colorado Beef Company and its Vice President, Walter Adams, have contributed the maximum possible effort toward making this project as useful, successful, and meaningful as could conceivably be expected. Virtually every request has been completely fulfilled in every respect and in a timely fashion. The data summarized in this report is only a brief example of the data collected during the course of the project. Constant attention to every detail and careful consideration of data to be taken and resulting data have resulted in completely comprehensive results that answer every imaginable question about the process so thoroughly evaluated. This organization and Walter Adams have gone far beyond the project requirements to assure that every aspect of the project was evaluated in the maximum possible quantitative detail.

In a similar fashion, Alwatech and its Process Department Head, Hans Chr. Isaksen, have contributed the maximum conceivable effort toward fulfilling every aspect of their portion of this project. During the course of this project, Mr. Isaksen as well as several other Alwatech personnel were on hand and constantly searching for ways to further improve the performance of this process both from the standpoint of wastewater treatment efficiency and maximum protein recovery. This organization and Mr. Isaksen spared no effort to see that their responsibilities were completely fulfilled to the maximum possible extent.

Dr. Stanley L. Klemetson of the Civil Engineering Department at Colorado State University wrote the following portions of the literature survey section 4: Anaerobic Lagoons; Combination Biological, Chemical and Physical Treatment System; Electrocoagulation (with J. C. Ward); and Protein Recovery by Ion Exchange.

SECTION 1

INTRODUCTION

SUMMARY

Beef packing effluents pose a considerable challenge to wastewater treatment technology. Several water quality parameters are listed below in Table 1 along with their average concentrations in domestic wastewater and the average concentrations observed in the effluent from this beef packing plant (from the last page of Table 32).

TABLE 1. COMPARISON OF BEEF PACKING AND DOMESTIC WASTEWATERS

Water Quality Parameter	Average Concentration, mg/l	
	in domestic wastewater	in beef packing effluent
COD	150	4,607
5-Day, 20°C BOD	140	2,945
Suspended Solids	235	2,462

Clearly the oxygen demand of beef packing effluent is 20 to 30 times that of domestic wastewater, so that at least 95% removal would be necessary to reduce the oxygen demand of beef packing effluent to that of untreated domestic wastewater. In addition, the quantity of suspended solids is over 10 times that of domestic wastewater. As a final complication, beef packing plants are not usually operated continuously, so that conventional biological wastewater treatment techniques leave a great deal to be desired.

This lack of continuous operation clearly indicates the desirability of a physiochemical wastewater treatment process. In addition, it would be highly desirable if some cost recovery were possible from the sale of the relatively large quantities of sludge that can be expected.

The Alwatech process is a physiochemical wastewater treatment process that also recovers protein (from the beef packing effluent) which can be sold to partially recover the cost of wastewater treatment. This process uses H_2SO_4 for pH reduction, Calcium lignosulfonate for protein precipitation, and $Ca(OH)_2$ for both effluent and sludge neutralization. Other methods of protein recovery are discussed in Section 4 and compared in

Section 9.

This report gives the results of a full scale evaluation of the Alwatech process installed at a beef packing plant in the United States. While the Alwatech process is not necessarily limited to treatment of and protein recovery from beef packing effluents, this report is based on beef packing effluent treatment and protein recovery. Other effluents treated by the Alwatech process include poultry processing and pig abattoirs.

UNIT WASTE PRODUCTION

Table 2 shows the unit waste production rates for 6 different waste products. From this table, it is clear that the quantities of the last three wastes listed are minor when compared to the quantities of the first 3 wastes listed. Because the average live weight of beef killed at this plant is 1,040 ± 15 pounds, the quantity of waste produced per 10^3 pounds is close to the quantity produced per head. About 350 gallons of wastewater are produced per head.

TABLE 2. UNIT WASTE PRODUCTION

Waste Produced	$\frac{\text{lb}}{10^3\ \text{lb}}$ *
5-day, 20°C BOD	6.51
Total suspended solids	5.44
Grease and oil	1.26
Organic nitrogen	0.28
Ammonia nitrogen	0.18
Phosphate	0.04

*lb/10^3 lb live weight killed

BRIEF DESCRIPTION OF THE PROCESS EVALUATED

The pH of the wastewater is reduced with sulphuric acid to between 2 and 3 (depending on the influent COD concentration). Calcium lignosulfonate is added to the wastewater in quantities that are directly proportional to the influent COD concentration. Following this protein precipitation step, the resulting floc containing protein,fat, and suspended material is separated by dissolved air flotation.

Following this separation, the pH of the liquid effluent is raised to about 4 (with calcium hydroxide) and then mixed with other wastewater streams that are not treated by this process. The pH of the resulting mixture is about 7 and consequently is suitable for additional treatment by conventional wastewater treatment processes. The sludge is also neutralized with calcium hydroxide to an initial pH of 9.1 which eventually drops to a pH of 7.6.

SCOPE OF THIS PROJECT

The major water quality parameters used to measure the effectiveness of this process are (listed in order of decreasing concentration):

COD
BOD
Total suspended solids
Total volatile solids
Volatile suspended solids
Grease and oil
Organic nitrogen
Ammonia nitrogen
Phosphate

The data summarized in this report covers a period of 8 months of operation. Because both the BOD and suspended solids loadings were 50% greater than the values used in the initial design, a certain amount of additional research and development work was necessary during this 8 month period.

Near the end of the 8 month data logging interval, 2 performance tests of 2 weeks each were conducted. Therefore the results obtained during these 2 trial periods may be a better indication of the performance of this process than the averages observed during the 8 month duration of the data collection summarized in this report.

SECTION 2

CONCLUSIONS

SUMMARY

For a beef packing effluent with an initial BOD averaging 3,000 mg/l, the Alwatech process is capable of removing over 80% of the oxygen demand, about 86% of the suspended solids, and 94% of the fat, oil, and grease (see Table 27 and the last part of Section 10). Average removals of 41% of the ammonia N and 63% of the organic N were observed. The solids concentration of the sludge produced by this flotation process averages about 9%.

The optimum Calcium Lignosulfonate dose is about 5% of the influent COD concentration although additional work may later show that this dose can be reduced somewhat. While the optimum pH range varies from about 2 to less than 3, for incoming COD concentrations greater than about 1,800 mg/l it is less expensive to use pH values nearer 2 because lower Calcium lignosulfonate doses can be used. While chemical costs increase as the influent COD concentration increases, the rate of increase is less at pH values near 2 (see Figure 17).

While the centrifuge efficiency was about 94% for water, it was only 52% for total solids, 66% for protein, 21% for oil and grease, and 76% for other solids (Table 47). When the centrifuge reject solution is recirculated back to the plant influent, the incoming COD is increased 32%, the influent suspended solids are increased 29%, and the influent grease and oil is increased 36% to 52% (Section 10).

Total observed operating costs were 47¢ per head or $1.68 per 1,000 gallons of wastewater treated (Table 54). About 2 pounds of protein were recovered per head, so this protein would have to sell for 23.5¢ per pound in order to cover all operating costs. However, operating costs could be reduced to 40¢ per head by using less Calcium Lignosulfonate. Calcium Lignosulfonate accounted for 39% of the total operating costs followed by 25% for labor, 15% for H_2SO_4, 10% for $Ca(OH)_2$, 9% for energy (1979), and 2% for repairs (Table 54).

Biological activity in the clarifier balancing tank preceding the Alwatech plant had an influence on oxygen demand and nitrogen removal efficiencies. This biological activity is believed due to the paunch and gut contents, relatively long detention time (1.5-2 hours), and high effluent temperatures (100° to 125°F). However, the detention time cannot be reduced below 1.5 hours as fat skimming and bottom sludge removal would both suffer.

The discharge of 5-day, 20°C BOD from this beef packing plant has been reduced to less than 3 pounds per head. For every pound of 5-day, 20°C BOD entering the Alwatech plant, an average of 0.77 pounds of product was recovered with an average composition of 38% protein, 11% grease and oil, 27% fixed solids, and 24% other solids on a dry weight basis.

MONTHLY AVERAGE EFFLUENT CONCENTRATIONS

The monthly average effluent concentrations were 806 ± 413 mg/l BOD, 46 ± 24 mg/l organic nitrogen, 41 ± 13 mg/l ammonia nitrogen, and 15 ± 11 mg/l phosphate where the first figure is the average (arithmetic mean) and the second figure is the arithmetic standard deviation. Both the grease and oil and the total suspended solids effluent concentrations were so variable (coefficient of variation >1) that they were better represented by a log normal (geometric) frequency distribution. Accordingly, the suspended solids effluent concentration geometric mean was 309 mg/l with a geometric standard deviation of 2.2. The grease and oil effluent concentration geometric mean was 40 mg/l with a geometric standard deviation of 4.8.

AMMONIA AND ORGANIC NITROGEN

The ratio standard deviation/mean for the influent ammonia and organic nitrogen concentrations was the same (0.48). The total nitrogen (ammonia + organic nitrogen) concentration averaged 210 mg/l with a standard deviation of 74 mg/l giving a standard deviation/mean ratio of 0.35 which indicates that the total influent nitrogen concentration was less variable. The average % removal of total nitrogen was 58% with a standard deviation of 21% giving a standard deviation/mean ratio of 0.36 which indicates the % removal of total nitrogen was also less variable. Total nitrogen = ammonia + organic nitrogen because it is assumed that nitrate plus nitrite nitrogen is negligible in comparison in this wastewater.

On the average, 41% of the influent ammonia nitrogen concentration of 82 mg/l was removed and 63% of the influent organic nitrogen concentration of 128 mg/l was removed. Consequently, the ammonia and organic nitrogen concentrations in the effluent were both about 48 mg/l each so that the total nitrogen effluent concentration was 95 mg/l.

An equation developed during the course of a laboratory investigation of protein recovery using Chitosan (1) was modified so that the % removal of organic nitrogen could be predicted as a function of temperature, pH, calcium lignosulfonate dose, and the COD concentration in the wastewater influent (equation 14). Comparison of the % organic nitrogen removals calculated by this equation with the observed data gave a correlation coefficient of 0.84. % COD removal and % organic nitrogen removal are linearly related (equation 15) with a correlation coefficient of 0.82.

PHOSPHATE AND FECAL COLIFORMS

The average % removal of phosphate was 49% which reduced the average influent concentration of 17 mg/l P to 9 mg/l P. A concentration of 6,600 fecal coliforms per 100 ml were observed in the effluent.

SOLIDS

28% of the total wet sludge volume produced is bottom sludge from the air flotation tanks. Total dried sludge production averaged 5 pounds per 1,000 pounds live weight killed. The dried sludge was 38% protein, 27% inorganic solids, 11% grease and oil, and 24% other. The solids concentration of the dried sludge was 88% and therefore the water concentration was 12%. The dried sludge is sold for use in animal feeds.

MATERIALS BALANCES OF POLLUTANTS

On the average, 27.5 gallons of wet sludge were produced per 1,000 gallons of wastewater treated. 90% of the wet sludge becomes centrifuge reject solution and 10% becomes dewatered sludge. The concentrations of COD, grease and oil, and suspended solids in the centrifuge reject solution averaged 50,000 mg/l, 5,860 mg/l, and 21,000 mg/l respectively. Consequently, pumping the centrifuge reject solution back into the plant influent increases the incoming COD 32%. 83% of the incoming COD is removed, and of the amount removed, 62% winds up in the dewatered sludge and the remaining 38% leaves in the centrifuge reject solution.

Based on separate disposal of the centrifuge reject solution, 81% of the suspended solids is removed, and of the amount removed, 64% winds up in the dewatered sludge and the remaining 36% leaves in the centrifuge reject solution. Consequently pumping the centrifuge reject solution back into the plant influent would increase the influent suspended solids 29%.

Again based on separate disposal of the centrifuge reject solution, 94% of the grease and oil is removed, and of the amount removed, 53% winds up in the dewatered sludge and the remaining 47% leaves in the centrifuge reject solution. The grease and oil concentration in the dewatered sludge is about 6%. Recirculation of the centrifuge reject solution back to the plant influent would increase the influent grease and oil by roughly 44%.

FILTER BELTS

Initially it was attempted to dewater the wet sludge using filter belts, but these were found to perform unsatisfactorily on the wet sludge produced, so they were replaced with a centrifuge.

ECONOMICS

Virtually all cost inputs to the process were measured including labor, cost of repairs and maintenance, energy, and chemicals. Operating costs were $1.68 per thousand gallons treated. The capital costs for an 800,000 gpd plant are an additional $1.32 per thousand gallons treated, so the total cost is $3.00 per 1,000 gallons treated. These costs do not give any credit for the protein recovered and sold.

About 2 pounds of protein are recovered per head. The average quantity of wastewater treated in the Alwatech plant was 276 gallons per head. Therefore the average cost of treating this wastewater was 83¢ per head, so that the protein recovered would have to sell for about 42¢ per pound of protein in order to recover all costs.

The wastewater treatment plant effluent pH averaged 3.8, but the wastewater discharged to the sewage treatment plant averaged 7 because of the effect of mixing the plant effluent with other wastewater streams from the beef packing plant. If the Alwatech wastewater treatment plant effluent had been raised to pH 7, this would have resulted in a needless increase of 10% in total costs.

The capital costs given (and consequently the total costs) include property taxes, interest, recovery of principal, and insurance.

SECTION 3

RECOMMENDATIONS

Means of reducing the operating cost of the Alwatech process should be investigated. While the pH should be near 2 for minimum operating cost, the calcium lignosulfonate dose need not exceed 5% of the influent COD concentration. The effect of lower doses on COD removal, and especially protein recovery should be studied.

R is the ratio of calcium lignosulfonate added (in mg/l) per mg/l of COD in the wastewater treatment plant influent. It appears that values of $R < 0.05$ do not give greatly reduced % COD removals, so it is believed that because of the cost of calcium lignosulfonate, it would be worthwhile to experiment with values of $R < 0.05$ even though (based on existing data) one could not recommend a value of $R < 0.05$ at this time.

The results of a detailed laboratory investigation of the use of chitosan are summarized in section 4 in the part entitled, "Protein Recovery Using Chitosan". A similar study should be done for calcium lignosulfonate, because the potential for significant reduction in operating costs is great. In addition, it is virtually impossible in a full scale operation (such as the one described in this report) to evaluate the effect of various plant operating practices on the sludge produced. Where protein recovery and hence financial recovery is possible, it is essential to know the effect of changes in operating variables on sludge production and characteristics.

Ways to increase the centrifuge efficiency for total solids as well as protein need to be investigated. The low protein efficiency (66%) of the centrifuge precludes separate treatment of the centrifuge reject solution unless one is willing to accept a 34% loss of potentially recoverable protein.

Before treatment by the Alwatech process, it may be desirable to have heavy solids and readily floatable grease removed by an efficient continuous screening system followed by a balancing tank with a relatively short detention time (say 30 minutes) to even out rapid variations in flow rate and wastewater quality. This might improve solids handling and sludge product quality.

For the reasons given in this report, both barometric condenser and stock pen wastewaters should bypass the Alwatech plant when protein recovery is an important objective.

While additional investigation of this process has been recommended above, the process is obviously ready to be used in its present state of development.

SECTION 4

LITERATURE SURVEY

The intent of this section is to survey the literature pertaining to treatment of beef packing effluent with special emphasis on protein recovery. Accordingly, the following treatment processes are discussed very briefly from this point of view:

Anerobic Lagoons
Combination Biological, Chemical, and Physical Treatment System
Dissolved Air Flotation (DAF)
Electrocoagulation

The remaining parts of this section deal specifically with protein recovery:

Protein Recovery by Ion Exchange
Protein Recovery Using Chitosan
Protein Recovery Using Lignosulfonate
Historical Development of the Alwatech Process
Theory of Precipitation with Lignosulfonate (LS)
The Use of Recovered Protein Concentrate as Animal Feed
Safety of LS Precipitated Proteins as Animal Feed Supplements
Protein Quality and Feeding Trials
General Description of the Alwatech Process
Alwatech Process Pilot Plant Results

Of the 78 papers, reports, etc. reviewed during the course of this project, 2 are particularly outstanding from the point of view of this project: The paper by Greiling (1) covering protein recovery using Chitosan and the paper by Foltz, Ries, and Lee (2)covering removal of protein and fat from meat slaughtering and packing wastes using lignosulfonate. Greiling's paper (1) is a model of the kind of laboratory work that needs to be done with lignosulfonate.

The paper by Foltz, Ries, and Lee (2) is the single most complete and detailed discussion of protein recovery from meat packing wastewaters using lignosulfonate that is currently available. It is definitely required reading for anyone interested in this process. Because of the enduring usefulness of this paper, the authors have utilized large portions of it in this report with only minor wording changes. An attempt has been made to give these authors the recognition they deserve where their work has been extensively quoted.

ANAEROBIC LAGOONS

The anaerobic lagoon can be used for the treatment of high-strength organic wastewaters that also contain a high concentration of solids. Generally these ponds are constructed by digging a hole about 10 feet deep in the earth and constructing the necessary inlet and outlet structures. The wastes added to the pond generally settle to the bottom and leave a dark supernatant which must be subjected to further treatment.

The organic loads are so high that the microbial oxygen demand in the ponds result in anaerobic conditions throughout. The anaerobic bacteria break down the complex organic matter in meatpacking plant wastes utilizing chemically bound oxygen. The stabilization process is achieved by a combination of precipitation and anaerobic conversion of organic wastes to CO_2, CH_4, organic acids, cell tissues, and other gaseous products. Typical operating parameters are presented in Table 3.

TABLE 3. OPERATING PARAMETERS (3)

Depth, ft	8 to 16
pH	6.8 to 7.2
Temperature, °F	43 to 122
BOD_5 Loading, lb/(acre) (day)	175 to 450
BOD_5 Removal	50 to 95%
Effluent Suspended Solids, mg/l	80 to 160

Anaerobic lagoons are capable of providing BOD, grease, and suspended solids removals in excess of 80 percent. Because the amount of mechanical equipment used is limited, the capital costs for construction are minimal and the operating and personnel costs are very small. The system is quite capable of withstanding both organic and hydraulic shock loadings.

A major disadvantage of the anaerobic lagoon as a treatment method is that odorous gases are produced as byproducts of the anaerobic decomposition. Hydrogen sulfide is one of the principle causes of the odor problem. The sulfate concentration of the water supply can significantly affect the amount of hydrogen sulfide produced. While the meat packing operation does not add significantly to this sulfate concentration, water supply concentrations in excess of 100 mg/l sulfate usually make the use of an anaerobic lagoon undesirable. Even this limit will not assure an odor free lagoon. The hydrogen sulfide released into the atmosphere will be approximately 1 percent of the sulfate mass in the entering wastewater stream. Where it is not possible to use water with a low sulfate concentration, it is possible to reduce the amount of hydrogen sulfide that escapes into the atmosphere by permitting the formation of a scum layer on the surface of the lagoon.

Applications

Anaerobic lagoons are most suitable as a method of pretreatment and are generally followed by units where the undesirable gases and organic byproducts are oxidized.

Baker and White (4) discussed the use of an anaerobic lagoon as a pretreatment method for a trickling filter. The system had an organic waste load of 29.3 lb BOD/1,000 ft^3 or 195% of the design load of 15 lb BOD/1,000 ft^3 and yielded the removal efficiencies shown in Table 4. The suspended solids removal efficiency was lower than expected but this was due in part to the overloaded conditions.

TABLE 4. ANAEROBIC LAGOON TREATMENT EFFICIENCIES (4)

	% Removal
BOD	82
COD	68
Grease	78
Total Solids	52
Suspended Solids	59
Volatile Solids	69

A second method involved the use of an aerobic lagoon following the anaerobic lagoon.

Wells, et al., (5) presented the results of using an extended aeration system following the anaerobic lagoon. The combined system BOD_5 removal efficiency ranged from 95 to 98 percent with an average of 97 percent. The corresponding suspended solids removal efficiencies ranged from 72 to 97 percent with an average of 90 percent. The anaerobic lagoon achieved an average BOD_5 removal efficiency of about 80 percent.

Byproduct Recovery

In general the anaerobic lagoon is of little use in the area of byproduct recovery. However, there are several gases produced: methane, carbon dioxide, and several sulfur compounds such as organic sulfides, disulfides and hydrogen sulfides (6).

The gas produced by an anaerobic lagoon is approximately 65 to 70 percent methane. It can be collected by covering the pond and pumping out the gas as produced. A floating flexible membrane cover was found to be the least expensive method of covering the lagoon and collecting the gases. The gas can be used to power a boiler to produce steam for packing plant use. About 12 to 18 cubic feet of gas are produced for each pound of volatile solids destroyed. The payoff for this energy conservation system varies from one to a few years (6).

COMBINATION BIOLOGICAL, CHEMICAL, AND PHYSICAL TREATMENT SYSTEM

The highly organic nature of meat packing wastewaters and the need for low cost treatment methods has resulted in the predominant use of biological treatment processes. Limited work has been conducted with physical and chemical methods such as air flotation, settling, and coagulation.

Applications

Hill and Dunkelberger (7) worked with a combination biological, physical, and chemical treatment system at the Roberts Packing Company. The wastewaters were from pork and pork product production. The treatment system consisted of the following: flotation of insoluble grease in catch basins, chemical treatment with ferrous sulfate and chlorinated lime, primary-rapid filtration with leelite sand filters, and secondary treatment by slow filtration through biological leelite sand filters. The wastewater concentrations were 2,400 mg/l BOD_5 and 1,400 mg/l suspended solids on kill days.

The catch basins used for grease removal had a 1.5 hour detention time. This allowed most of the flotable materials to be removed except those with very slow rise times. These materials can be sold as renderable materials and amounted to about 100 gallons per day.

Chemical precipitation was carried out in 20,000 gallon batch tanks. The typical chemical doses were 100 lb lime, 100 lb ferrous sulfate, and 25 lb chlorinated lime. The tank was mixed 10 minutes and allowed to settle for three hours. The settled sludge was disposed of in a landfill and the effluent received further treatment. This unit reduced the BOD_5 concentration about 50 percent.

The effluent was treated by primary filtration in a system constructed with leelite sand. The primary filters reduced the BOD_5 concentration to 500 mg/l and suspended solids concentration to 20 mg/l.

Secondary filtration was a slow flow process that encouraged biological growth. The large filter area, low loading rates, and oxygen from the atmosphere achieved high BOD_5 removal. The overall reductions were 95 percent for BOD_5, 95 percent for suspended solids, and 95 percent for total phosphates.

The multi-mode treatment system permits recovery of the grease in the wastewater and provides good treatment efficiency. The chemical coagulation process reduces the waste strength significantly and permits the following units to be much smaller.

Stephenson (8) reported on the operation of a New Zealand meat packing plant. The process consisted of a chemical coagulation process that removed most of the organic and suspended material remaining after primary treatment. The process used sulfuric acid to reduce the pH to the isoelectric point followed by the addition of a phosphate coagulant. A lime slurry was used to raise the pH and promote coagulation. The effluent was gently stirred in the flocculator-clarifier to promote growth of large floc. The settled solids were thickened, heated, centrifuged, and dried. The performance of the system is summarized in Table 5.

TABLE 5. TREATMENT EFFICIENCY AND BYPRODUCT RECOVERY* (8)

Component	Composition %	mg/l Primary Effluent	mg/l Secondary Effluent	Removal %
Chemical Oxygen Demand		2,765	535	81
Total Solids		2,525	1,855	27
Suspended Solids		1,235	60	95
Total Organics		1,705	700	60
Ash Content	25	820	1,155	-41
Total Grease	27	550	20	96
Protein as NX6.25	31	795	370	53
Other Organics	17			
pH		7.5	9.0	

Based on pilot plant data, typical costs for the treatment of the wastewater from the catch basin was $0.20/1,000 gal (April 1976, U.S. prices) for chemicals and $0.22/1,000 gal for utilities. About 40 to 60 percent of the capital costs are due to the recovery equipment.

DISSOLVED AIR FLOTATION (DAF)

The first 3 lines of data in Table 6 are a summary of data reported by Chittenden (9).

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*This table contains data from extensive laboratory and pilot plant studies at 5 different meat packing plants.

TABLE 6. PERFORMANCE OF DAF UNITS TREATING BEEF PACKING HOUSE WASTES

Overflow Rate gpm/ft^2	Grease		Suspended Solids	
	Influent Concentration, mg/l	% Removed	Influent Concentration, mg/l	% Removed
0.77	1,715	50	1,705	34
1.667	1,365	58	1,675	61
-	363	55	-	-
Dissolved Air Flotation Pilot Plant (Table 22)	424	51	828	60

The last line of data in Table 6 is taken from Table 22. While the influent concentrations differed substantially, the % removals are about the same.

Because the data in Tables 6 and 22 represent all the data on DAF treatment of beef packing house wastes that the authors could obtain, additional data is presented on treatment of hog slaughterhouse wastes (10), poultry processing wastes (11), and shrimp canning wastes (12) by DAF.

The results of DAF treatment of hog slaughterhouse wastes and poultry processing wastes are shown in Table 7. The results of treating shrimp canning wastes with a DAF pilot plant are shown in Table 8. The best results (70% COD removal and 86% total suspended solids removal) were obtained at a pH of 5, a dose of 60 mg/l aluminum sulfate, and a concentration of 4 mg/l of polymer.

TABLE 7. DAF TREATMENT OF HOG SLAUGHTERHOUSE AND POULTRY PROCESSING WASTES

Wastewater Parameter	Poultry Processing Wastes		Hog Slaughterhouse Wastes	
	Influent Concentration, mg/l	% Removal	Influent Concentration, mg/l	% Removal
Grease	144	56	1,484	62
BOD	390	28	2,624	33
COD	936	34	4,591	11
Suspended Solids	390	45	2,223	32
Total Solids	729	29	-	-

TABLE 8. DAF TREATMENT OF SHRIMP CANNING WASTES

			COD		Total Suspended Solids	
pH	Aluminum Sulfate, mg/l	Polymer (Magnifloc 835A), mg/l	Influent concentration, mg/l	% Removal	Influent concentration, mg/l	% Removal
5	0	4	-	-	600	0
5	50	4	3,200	53	585	25
5	60	4	4,100	70	613	86
5	75	0.5	3,200	64	625	82
5	75	1	3,600	65	560	78
5	75	2	3,300	64	355	86
5	75	4	3,500	64	664	85
5	75	5	3,400	61	590	81
5	75	10	3,400	56	510	31
5	100	4	3,600	58	333	80
5	150	5	4,000	65	427	64
5	150	10	3,400	53	620	66
6.2	300	4	4,000	50	1,135	80
6.5	150	4	3,100	44	344	7

ELECTROCOAGULATION

The principal deterent to natural removal of pollutants by settling is size and charge. All wastewaters contain electrically charged materials in a finely divided form that are too small and light to settle out in a reasonable time. These particles range in size from 1/2 to 50 microns and are defined as suspensions, dispersions, and emulsions. They are usually negatively charged.

All of the reported information on electrocoagulation refer specifically to the LECTRO-CLEAR process developed by Swift and Company. The process consists of an electrocoagulation cell which conditions the wastewater before it enters the flotation tank, and an electrolytic flotation grid that raises any residual floc from the wastewater. Both systems use a low voltage (6 to 10 volts) and a relatively high current. It is not necessary to use both systems at the same time but it is recommended for heavily polluted waters. (13).

The principle of operation of the two-step electrocoagulation process is summarized below. The first step is the mixing of coagulant and pH adjustment chemicals prior to introduction of the wastewater into the electrocoagulation or contact cell. In this cell, 50 to 100 micron diameter microbubbles are produced electrically. A two minute dwell time is allowed for mixing of bubbles and pollutant particles. Upon leaving the cell, a polymer is added and a gross floc is formed in the flotation basin.

The flotation basin is the second step of the electrocoagulation process. The detention time is about 25 minutes and electrolytic microbubbles are produced to float the particulates to the surface of the water. Better than 80 percent of these bubbles are captured by the floc. The current required is about 5 ampere minutes per gallon in the contact tank and about 4 ampere minutes per gallon in the flotation tank. The voltages used are DC and range from 10 to 15 volts. Skimmed solids ranged from 13.7 to 17.5 percent (14, 15).

Ramirez and Johnson (16) found that in the case of packinghouse wastewaters the charge on the surface of the pollutant particles approaches zero at a pH of 4.5. This pH is very close to the isoelectric point of blood. At the isoelectric point blood curdles which makes it readily available for removal from the wastewater. They state that the pH of 4.5 results in effective flotation of fats and oils as well as suspended materials from the wastewater. In addition, coalesence of the particulates is taking place due to the zero charge on the pollutant particulates.

Using a raw packinghouse wastewater and an energy input of 10 ampere-minutes per gallon, the concentrations of both fats and oils as well as turbidity in the treated wastewater was minimized at a pH of 4.5. These results are given in Table 9.

TABLE 9. PACKINGHOUSE WASTEWATER TREATMENT AT pH 4.5

	Influent Concentration	% Removal
Fats and Oils	1,800 mg/l	98
BOD	2,200 mg/l	80
Suspended Solids	2,250 mg/l	95
Turbidity	2,600 JTU	97

In another paper, Ramirez and Clemens (17) showed that zero charge is obtained at a pH of about 4.75 (at 87°F) for meat processing wastewater. They also showed that the concentration of fats and oils as well as turbidity in the treated effluent was minimized at a pH of 4.75. These results are given in Table 10.

These 2 papers do seem to establish that the best treatment is obtained at the pH corresponding to zero charge, and this pH appears to be between 4.5 and 4.75.

TABLE 10. MEAT PROCESSING WASTEWATER TREATMENT AT pH 4.75

	Influent Concentration	% Removal
Fats and Oils	1,900 mg/l	98
Suspended Solids	2,400 mg/l	96
Turbidity	2,900 JTU	100

Applications

Ramirez (18) experimented with the electrocoagulation process. Using a wastewater with a BOD_5 concentration of 6,000 mg/l, FOG of 4,200 mg/l, suspended solids of 1,500 mg/l, an effluent with BOD_5 concentration of 250 mg/l, FOG of 20 mg/l, and total suspended solids of 80 mg/l was achieved using 300 mg/l of aluminum sulfate and 1 mg/l of a polyelectrolyte.

Ramirez (18) reported on the installation of the electrocoagulation process at a meat packing plant in Grand Island, Nebraska. The wastewater flow of 1.2 mgd was introduced into two dissolved air flotation tanks at the rate of 600 gpm. The influent concentrations were 3,250 mg/l BOD_5, 1,230 mg/l suspended solids, and 860 mg/l fats, oils, and grease. The chemicals added were 500 mg/l of ferric sulfate, 200 mg/l of calcium hydroxide, and 1/2 mg/l of a polyelectrolyte. The effluent characteristics were 110 mg/l BOD_5, 100 mg/l suspended solids, and 20 mg/l FOG. The cost of the electrical portion of the system was $9,500 per basin and the power cost was $4.20 per day per basin. The power cost averaged about 1/2 cent per 1,000 gallons of wastewater treated.

Ramirez and Clemens (15) evaluated the operation of the electrocoagulation system in a rendering operation. The wastewater involved had a zero zeta potential at a pH of 4.2. When the wastewater was acidified to pH 4.2 and allowed to settle for 1/2 hour, the turbidity was reduced from about 10,000 JTU to around 500. When 6 mg/l of an anionic polymer and 5 ampere-minutes at 12 volts were also used, the turbidity was reduced further to 300 JTU. Using 500 mg/l of ferric sulfate or aluminum sulfate, 6 mg/l anionic polymer, and a power input of 2 ampere-minutes, the turbidity was reduced to 50 JTU. Their evaluation of the system indicated that the most cost effective system used 500 mg/l H_2SO_4, 300 mg/l aluminum sulfate, and 6 mg/l of anionic polymer in conjunction with the power application. The chemical costs were 47¢ per 1,000 gallons.

Comparison of 3 Types of Electrocoagulation

Clemens (19) described 3 types of electrocoagulation systems to treat packinghouse or food wastewaters:

1. Use of a trivalent metal coagulant (like aluminum sulfate or ferric sulfate) to neutralize negative surface charges, addition of calcium hydroxide to raise the pH, electrocoagulation, polymer addition, followed by electroflotation.

2. A small quantity of trivalent metal coagulant is added (100 mg/l) followed by sulfuric acid to obtain zero surface charge, electrocoagulation, polymer addition, followed by electroflotation.

3. Sulfuric acid addition to reduce the wastewater pH to obtain zero surface charge, electrocoagulation, polymer addition, followed by electroflotation. This is the Lectro Clear Z process (no metal coagulants).

Results obtained at a beef slaughtering plant (20) are given in Table 11. From the foregoing description of the 3 types of electrocoagulation, it is clear that despite differences in the preliminary steps, the last 3 steps are the same: (1) electrocoagulation, (2) polymer addition, and (3) electroflotation. Consequently, the data in Table 11 shows the effect of the different preliminary steps on the quality of the wastewater treatment plant effluent. Comparison of the results given in Table 11 with

TABLE 11. COMPARISON OF 3 TYPES OF ELECTROCOAGULATION *

Preliminary treatment steps that are followed by electrocoagulation, polymer addition and electroflotation	BOD		Suspended Solids		Fats, Oils, and Greases	
	Influent	% Removal	Influent	% Removal	Influent	% Removal
1. Addition of a trivalent metal coagulant to neutralize negative surface charges, addition of calcium hydroxide to raise the pH.	1,600	90	975	90	460	96
2. About 100 mg/l of trivalent metal coagulant is added followed by sulfuric acid to obtain zero surface charge	1,600	89	975	89	460	95
3. Sulfuric acid is added to reduce the wastewater pH to obtain zero surface charge	1,000	79	840	94	354	97
Average results obtained by Alwatech Pilot Plant (Table 22)	1,045	81	770	90	382	96

* Influent concentration in mg/l

those given in Table 22 indicate that, as far as waste water treatment goes, electrocoagulation and the Alwatech process are roughly comparable in efficiency.

A cost comparison of the 3 types of electrocoagulation indicates that the labor costs are about the same for all 3 types. The capital costs and electricity cost for the first 2 types listed in Table 11 are about the same, while the capital costs for the third type are 22% more, and the electrical consumption is 5 times as great. Chemical costs for the first type of electrocoagulation are about 78% more than for the second and third types which are roughly the same.

PROTEIN RECOVERY BY ION EXCHANGE

Protein is a main contributor to the pollution load from a meat packing facility. It is a complex molecule with a high molecular weight. While this results in high treatment costs, it can also mean potential reduction in treatment costs due to byproduct recovery. One method of protein recovery was developed by the Viscose Company. It is called the Vistec protein recovery system and uses cellulose ion exchange media manufactured from regenerated cellulose.

Applications

The Vistec protein recovery system was discussed by Jones (21). It uses a dynamic ion exchange process consisting of three stages: protein adsorption, protein recovery, and media wash. Because the media are in a particulate form and functions as a moving bed ion exchange process, it does not suffer some of the problems of conventional ion exchange units, such as compression, channeling, and clogging.

A continuous stirred reactor is used to mix the regenerated media and influent for 20 to 30 minutes. The overflow passes to a settling tank where the aqueous phase is separated from the media containing the protein.

In the second stage, the ion exchange media is regenerated with a salt solution or by pH adjustments. The effluent of the settling tank now contains a concentrated solution of protein. The settled regenerated media is then washed free of regenerant salt solution for further protein adsorption.

A pilot plant operating at 10,000 gallons per day has been operated at British Beef Abattoir, Watford. Over 85 percent of the protein was consistently removed from the wastewater stream, and, in some cases, the efficiency increased to 95 percent. Treatment of the concentrated protein stream depends upon the form of the recovery product desired.

PROTEIN RECOVERY USING CHITOSAN

Greiling (1) reported on the laboratory recovery of soluble serum proteins from meat industry wastes. He pointed out that blood is the largest single waste originating on the killing floor and (in terms of BOD) is the strongest pollutant in the entire meat packing industry. He noted that the Federal Food and Drug Administration does not allow the feeding of ruminants or other animals any feedstuffs chemically removed with synthetic polyelectrolytes. This constraint led to his investigation of the serum protein recovery capabilities of the organic polymer chitosan.

In his work, Greiling (1) used chitosan, an organic polymer composed of glucosamine residues, to help remove suspended protein aggregates from solution. Greiling pointed out that chitosan has been shown to be an effective coagulant aid with protein-containing wastes. Approval for its use as a polymer for industrial applications and subsequent marketing in feedstuffs is pending before the Food and Drug Administration (22).

Greiling (1) noted that the net ionic charge of the protein molecule changes with pH, and that protein mobility is zero at the isoelectric point. In his work, he noted that protein recovery is much greater near the isoelectric point than at higher pH values. He observed that a temperature of 60^{o}C (140^{o}F) decreased the quantity of protein recovered compared to that at 20^{o}C (68^{o}F). Because this result is opposite that expected, he hypothesized that protein solubility increased with temperature. Statistical analysis of his data suggested that thermal denaturation must occur above 60^{o}C (140^{o}F).

In Greiling's study (1), protein removal was enhanced with increasing polymer dosage up to a chitosan concentration of about 100 mg/l. For chitosan concentrations greater than 100 mg/l, he observed a leveling off of the yield of protein recovered because the proteins remaining in solution appeared to be no longer influenced by the presence of the chitosan. At low chitosan concentrations, Greiling (1) obtained the maximum recovery of proteins well below the isoelectric point of the protein solution. At a chitosan concentration of 100 mg/l, protein recovery was maximized at somewhat higher pH values. He stated that the residual protein concentration was most likely limited by protein solubility.

Greiling determined that a minimum temperature of about 60^{o}C (140^{o}F) is required for thermal denaturation of proteins (theoretically, thermal denaturation of all proteins occurs at 100^{o}C). He stated that protein solubility in high dissolved salt solutions must limit protein recovery efficiencies.

From his data, Greiling (1) developed the following equation (multiple correlation coefficient = 0.943):

$$F = 0.54T + 52\ pH - 6.6\ (pH)^2 - 0.44D$$
$$-0.091\ T(pH) + 0.12\ D(pH) - 60 \qquad (1)$$

where

F = organic nitrogen removal efficiency, %

T = temperature, ^{o}C

D = dose, mg/l chitosan

It is interesting to note the organic nitorgen removal efficiency for the case D = 0 mg/l chitosan. For D=0, equation 1 becomes

$$F = 0.54T + 52\ pH - 6.6\ (pH)^2$$

$$- 0.091\ T(pH) - 60 \qquad (2)$$

For a given temperature T, the optimum pH can be determined as follows:

$$\frac{dF}{d(pH)} = 52 - 13.2\ (pH) - 0.091T = 0 \qquad (3)$$

$$\frac{d^2F}{d(pH)^2} = -13.2 < 0. \qquad (4)$$

Because $d^2F/d(pH)^2 < 0$, the pH value given by equation 3 will make F a maximum. Consequently, the optimum pH is

$$pH = 3.94 - 0.00689T \qquad (5)$$

Substituting equation 5 into equation 2 gives the maximum value of F that can be obtained at a given temperature for D = 0 and a pH given by equation 5:

$$F = 43 + 0.18T + 0.000314T^2 \qquad (6)$$

For temperatures T in the range of 0 to 80°C (32 to 176°F), equation 6 can be approximated as follows:

$$F = 43 + 0.2T \qquad (7)$$

Equations 5 and 7 are shown in Figure 1.

Greiling (1) also conducted a laboratory investigation to see if dissolved protein removal, beyond that recovered by denaturation and polymer coagulation, could be achieved with activated carbon. He observed

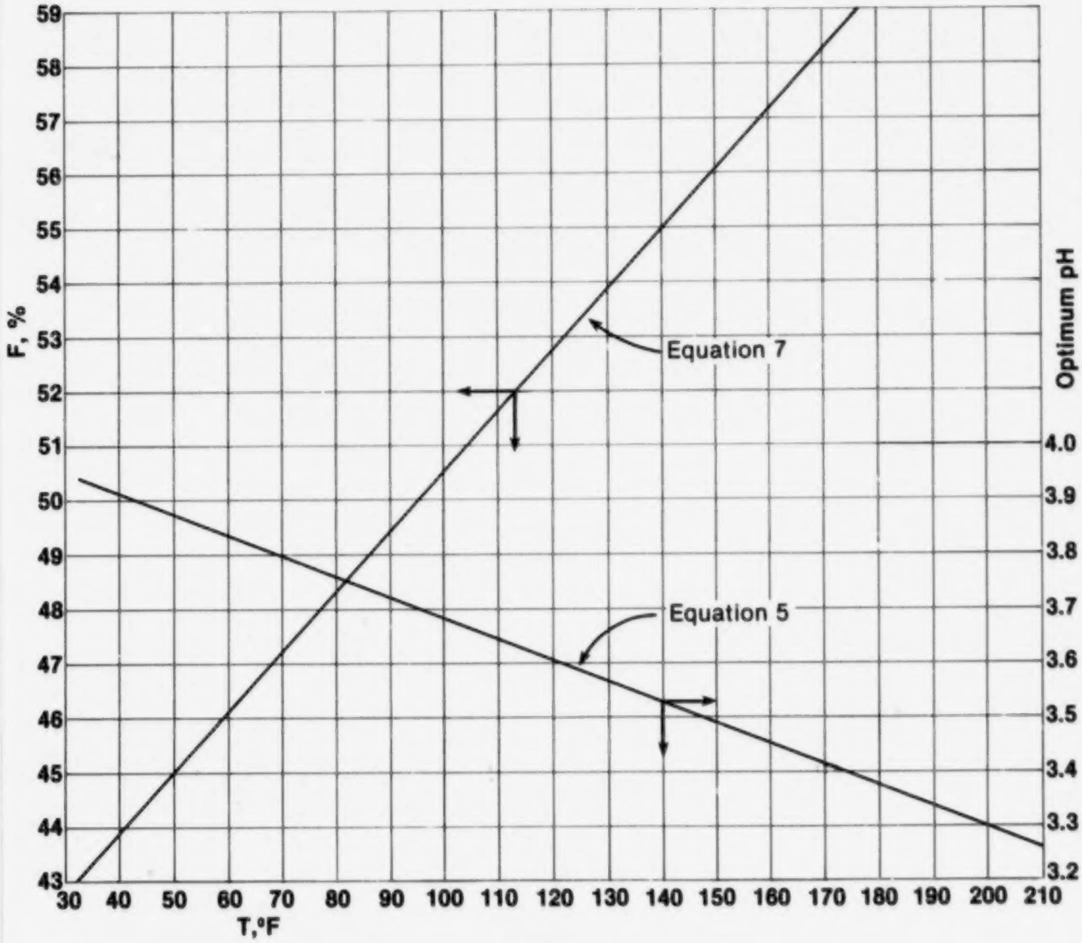

Figure 1.
Organic Nitrogen Removal Efficiency at Optimum pH for a Chitosin Dose of Zero

that carbon adsorption removal improved with increasing dissolved organics concentration and that protein removal by activated carbon is significant.

Greiling (1) estimated costs for a recovery system treating the serum waste stream from a blood centrifuge. In this system, pH and thermal denaturation, and protein coagulation are followed by evaporation of the settled solids. The resulting solids are marketed and the supernatant is wasted. This system operated at a pH of 4.6, a temperature of 60°C (140°F), and used a chitosan dose of 100 mg/l. Table 12 contains the influent concentrations and % removals observed. The costs associated with this system are shown in Table 13.

TABLE 12. INFLUENT CONCENTRATIONS AND % REMOVAL USING CHITOSAN AND ACTIVATED CARBON (1)*

Activated Carbon Dose g/l	0	0	4	8	20	40	80	160
	Influent Concentration mg/l	% Removal						
COD	12,400	37	43	53	75	81	91	94
Organic Nitrogen	1,760	61	77	84	88	92	96	97
Total Solids	23,800	65	64	67	70	72	72	70
Volatile Solids	16,200	75	78	83	87	91	93	93

*Serum waste stream from a blood centrifuge.

TABLE 13. COSTS ASSOCIATED WITH THE TREATMENT RESULTS SHOWN IN TABLE 12 FOR 0 g/l ACTIVATED CARBON (1)*

	$ per 1,000 gal.
Chemicals -	
Chitosan: 0.16 lb/(1,000 gallons) at $5 per lb.	0.80
Acid: 1.3 l concentrated $H_2SO_4/10^3$ gal. at 90¢ per liter	1.17
Steam -	
Heat Exchanger: 640 lb/10^3gallons at $3.50 per 1,000 lb.	2.24
Evaporation: 680 lb/10^3gallons	2.38
Capital recovery (10 years, 10%, 250 work days per year)	0.84
Neutralization and Treatment of Supernatant	1.00
Total operating expenses excluding labor and carbon adsorption	8.43
Salable recovered protein feedstuffs - 68 lb/1,000 gallons at 10¢/lb	6.80
Steam savings from present evaporation facilities - 7,810 lb/1,000 gallons at $3.50 per 10^3 lb	27.34
Total Savings	34.14
Total Savings - Total Costs (excluding labor and carbon adsorption)	25.71

*Serum waste stream from a blood centrifuge.

One of Greiling's (1) conclusions was that high dissolved salt concentrations may tend to limit protein recovery because of protein solubility in saline solutions.

PROTEIN RECOVERY USING LIGNOSULFONATE

Currently the only chemical that has full scale demonstration of protein recovery from wastewaters is lignosulfonate. This process was developed by Alwatech A/S of Norway, and lignosulfonate is marketed under the trade name of Alprecin in Europe. The Sterling Colorado Beef Company is the first in the United States to use this process to treat their wastewater.

Regardless of their source, the ultimate analysis of all proteins falls within a very narrow range (23):

Element	%
Carbon	51-55
Hydrogen	6.5-7.3
Oxygen	20-24
Nitrogen	15-18
Sulfur	0-2.5
Phosphorus	0-1

The nitrogen content averages about 16%. Because carbohydrates and fats do not contain nitrogen, the value for organic nitrogen when multiplied by (100/16=) 6.25 gives an estimate of the protein content.

Over the years, numerous papers have been written dealing with protein recovery using lignosulfonate (24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35). Because this process is the subject of this report, only those papers dealing with aspects not adequately covered by this report will be reviewed.

Foltz, Ries, and Lee (2) used the abbreviation LSA to represent lignosulfonic acid. LSA products are available in the salt form such as sodium, calcium, or ammonium lignosulfonate. Because the cation is not involved in precipitation, the choice of salt form is dictated by reasons other than precipitation performance.

On the other hand, ammonium lignosulfonate would be clearly unsuitable where nitrogen removal was an objective. Calcium lignosulfonate was used at the Sterling Colorado Beef Company plant. Sodium lignosulfonate has been called "Alprecin".

Protein recovery using lignosulfonate is a physical-chemical process that removes protein and fat from meat slaughtering and packing operations wastewaters. These wastewaters have high concentrations of BOD, suspended solids, grease or fat, and nitrogen. In fact, the main constituents are proteins and fat that are animal body fluids and tissue. These wastewaters are usually warm, have a pH near 7, contain nutrients, and are readily biodegradeable so that biological wastewater treatment methods have been successfully used to produce effluents with low concentrations of BOD, suspended solids, and grease. However, most biological wastewater treatment systems were not designed to remove the nitrogen present. A process that removes protein from wastewaters directly removes nitrogen in its original state. Protein recovery using lignosulfonate appears suitable as a pretreatment step to biological treatment.

The physical-chemical combining of lignosulfonate and proteins in an aqueous system has been known for over 35 years (2). Since 1970, Alwatech A/S has marketed equipment and technology in Europe for recovery of proteins from wastewater on an industrial scale.

Barnett and Nelson (36) and Ertz, Atwell, and Forsht (37) studied the effects of adding $Al_2(SO_4)_3$ and $Ca(OH)_2$ to wastewater produced in the seafood processing industry prior to the dissolved air flotation process. Foltz, Ries, and Lee (2) stated that aluminum sulfate is less effective than lignosulfonate for nitrogen removal, but is effective for phosphate removal.

Foltz, Ries, and Lee (2) point out that lignosulfonic acid is a by-product from the sulfite wood pulping industry and is commercially available in a variety of forms and quality.

Spent sulfite liquor contains wood lignin that has been made soluble by the sulfonate groups in the lignin. Sulfonated lignins are large molecules made up of repeating units of polymerized coniferyl alcohol along with lesser quantities of sinapyl and p-coumaryl alcohols (sinapyl alcohol contains 2 aromatic methoxyl groups while p-coumaryl alcohol has none). About half the coniferyl units are sulfonated, primarily on the aliphatic carbon attached to the aromatic ring (2). Figure 2 illustrates a typical segment of sulfonated lignin. The term "lignosulfonate" or LS is used herein to describe the sulfonated lignin matter as present in an aqueous system, which is ionized as shown in Figure 2.

Foltz, Ries, and Lee (2) point out that the molecular weight of lignosulfonate is not a defined quantity because the commercially available materials are mixtures of various molecular weight lignins:

LS Fraction	Average Molecular Weight
α	14,620
β	5,180

In protein precipitation, the α fraction is more suitable than the β fraction (2).

Foltz, Ries, and Lee (2) state that spent sulfite liquor is over 50% lignosulfonate on a dry weight basis, and is capable of precipitating proteins, but contains carbohydrates that contribute soluble BOD. Desugared sulfonated lignins are commercially available and are better precipitants for wastewater protein. The most suitable precipitating chemical is more highly purified lignosulfonate.

Calcium lignosulfonate is available as a dry powder in 50 lb. bags. It is not a standard chemical, but rather a complex mixture of sulfonated lignins plus minor wood extract impurities. According to Foltz, Ries, and Lee (2), differences in the woods used, method of cooking, and

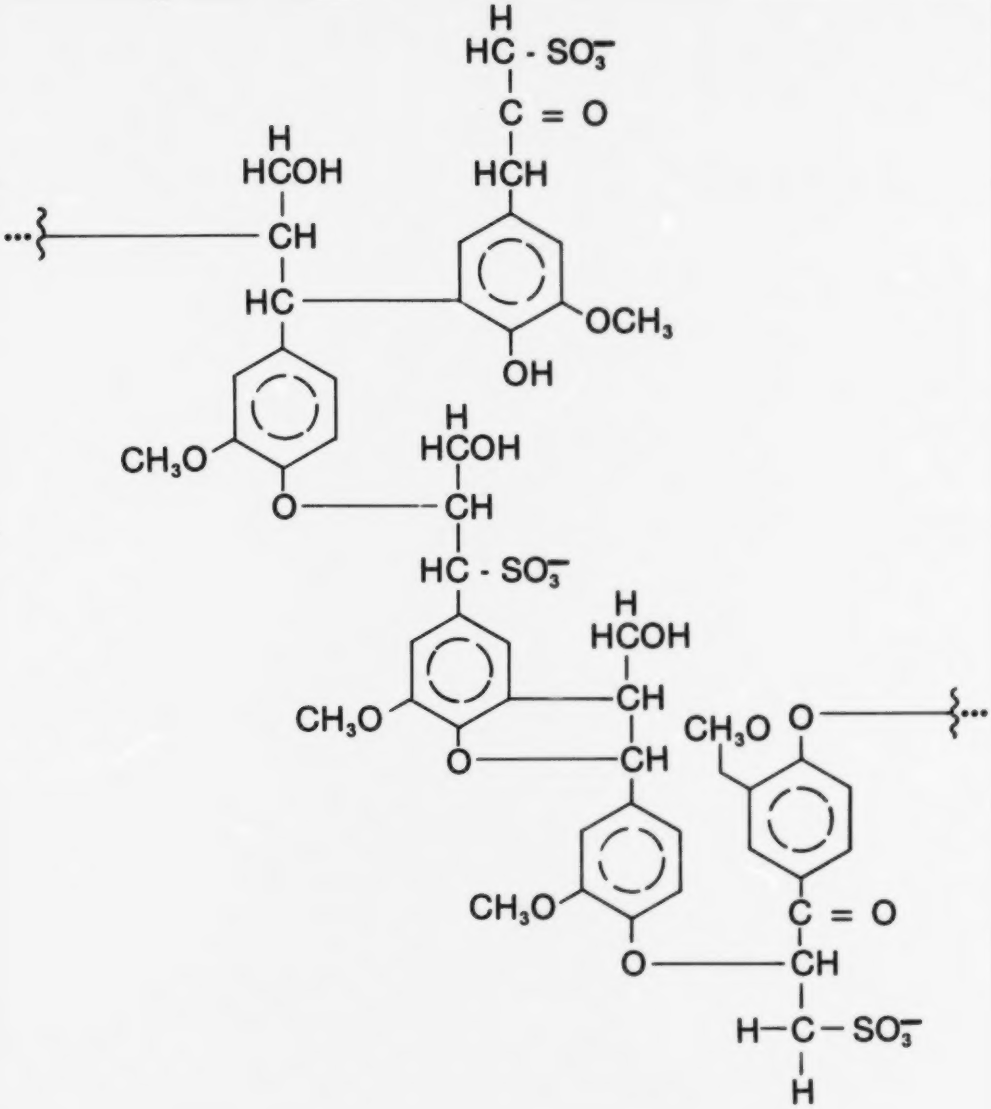

Figure 2.
Typical Segment of Sulfonated Lignin Molecule [from Foltz, Ries, and Lee (2)].

subsequent handling will affect the properties of LS. LS is applied as a 10% total solids solution which results in a blackish-brown liquid that is easily handled and pumped. Lignin sulfonates are FDA approved for use in animal feed as described in the Code of Federal Regulation, 21CFR121.234.

Foltz, Ries, and Lee (2) reported an analysis of an LS sludge from some pilot plant studies as follows:

	% of dry matter
Protein	40
Fat	24
Crude Fiber	4
Lignin Sulfonate	32
Total	100

Non-protein nitrogen constituted only about 8% of the total nitrogen.

Some of the conclusions listed by Foltz, Ries, and Lee (2) are:

1. The process appears best applied to a very fresh wastewater of high protein concentration where inedible rendering operations can be used to handle the recovered dewatered sludge.

2. Various LS products are commercially available from several suppliers that are suitable for protein precipitation.

Hustad (38) reported the specific precipitation effects of 7 different lignosulfonates. His results are shown in Table 14. The pH of most of the 10% solutions was around 7, with the notable exception of 2C. All of the initial COD values he used were less than half the average initial COD values observed during the course of this project. The ratio $\frac{\text{mg/l LS added}}{\text{mg/l influent COD}}$ shown in column 4 were over 4.5 times as great as the average used in this project. % COD reductions were impressive for Product 1 (93% average), 2E (94% average), and 2F (94%). The COD reductions observed for 2A and 2C were little better than the average observed in this project, while the COD reductions of 2B and 2D were somewhat better. The % COD reduction appears to be related to the specific precipitation effect values given in column 6 of Table 14. During the course of this project however, the average specific precipitation effect observed was 8.43, a value 4 times greater than any Hustad observed.

TABLE 14. PROPERTIES OF VARIOUS LIGNOSULFONATES (38)*

Product (1)		pH of 10% solution (2)	Initial COD, mg/l (3)	mg/l LS added / mg/l influent COD (4)	% COD Reduction (5)	mg/l COD reduction / mg/l LS added (6)	mg COD / mg LS (7)
Product 1			1,796	0.557	93	1.66	
			1,829	0.547	92	1.69	
			1,829	0.656	93	1.42	
			1,944	0.514	94	1.84	
	mean	6.8			93	1.65	0.29
Product 2	2A	7.1	1,829	0.656	74	1.13	0.3
	2B	6.7		0.547	87	1.59	
	2C	8.5		0.656	76	1.16	
	2D	6.9		0.547	90	1.65	
	2E		1,796	0.445	94	2.11	
				0.557	94	1.7	
	mean				94	1.91	0.66
	2F		1,944	0.463	94	2.03	0.2
	mean						0.36

*This is a comparative test procedure.

The values listed in column 7 are of special interest. These values are the mg of COD added to the effluent COD per mg of LS added in excess of stoichiometric requirements. Apparently the COD (in mg/l) of unreacted lignosulfonates averages 36% of the LS concentration in mg/l. Hustad's results (38) show that nothing is gained by adding lignosulfonates in excess of stoichiometric requirements and also that the effluent COD is actually increased somewhat by unreacted lignosulfonate.

HISTORICAL DEVELOPMENT OF THE ALWATECH PROCESS

The basic research work leading up to the Alwatech process started in Oslo, Norway, as early as 1960. At that time Leif Jantzen et. al.(39) developed a method for separating pure high molecular weight lignosulfonate (LS) from sulphite liquor, and during studies of the properties of pure LS, the ability of LS to precipitate soluble proteins from dilute aqueous solutions was found to be a very promising application.

Additional studies of the LS precipitation of proteins resulted in a patented method. On the basis of this patented method, Alwatech developed an industrial process using LS precipitation of proteins for the treatment of wastewaters and recovery of proteins from abattoir, fish, and poultry plants.

There are currently (1979) 50 Alwatech A-S installations around the world. Of these, 15 use essentially the same treatment process as the process installed at Sterling Colorado Beef Company: chemical precipitation, dissolved air flotation, sludge concentration, and protein and fat recovery. The 10 installations serving cattle abattoirs are in Sweden, England, Poland, Scotland, Republic of Ireland, Northern Ireland, and the U.S.A. The installations serving poultry processing and pig abattoirs are in Sweden, Belgium, England, and South Africa.

THEORY OF PRECIPITATION WITH LIGNOSULFONATE

Foltz, Ries, and Lee described protein precipitation with lignosulfonate in their paper dealing with removal of protein and fat from meat packing wastewaters (2). All of the following material in this section was taken from their paper and much of it is quoted directly from their paper and the rest is paraphrased.

They state that the precipitation of soluble protein with soluble lignosulfonate (LS) in an acidic aqueous system is a nearly instantaneous reaction involving the negatively charged sulphonate groups on the LS molecules and positively charged amine groups present on the protein molecules. The complexing of these large molecules results in a gelatinous suspended material that can be removed by a suitable liquid-solids separation technique.

Protein molecules contain both positively charged amine groups and negatively charged carboxyl groups when the solution is at pH values near 7. Acidification of proteinaceous wastewater to pH values below the isoelectric point will result in proteins carrying a net positive charge. Isoelectric values vary with different proteins, but acidification to pH 3.5 or below normally insures a pH below the isoelectric point for most protein aqueous solutions.

Foltz, Ries, and Lee (2) point out that when LS is in an aqueous solution, the sulfonate group is essentially completely ionized, resulting in a net negative charge on the LS molecule. With acidification, the strong acid group of the sulfonate continues to carry a negative charge even at pH values of 2 to 3. At pH values below 1, the sulfonate group begins losing its charge.

Table 15 summarizes the net charges on LS and protein molecules at various pH ranges, along with the resulting precipitation potential.

TABLE 15. EFFECT OF pH ON PROTEIN PRECIPITATION BY LS
(AFTER FOLTZ, RIES, AND LEE (2))

pH Range	Protein Charge	LS Charge	Precipitation Results
0-1	Positive	Weak Negative	Poor
2-3	Positive	Negative	Good
3.5-4.5	0 (Isoelectric Point)	Negative	Poor
>4.5	Negative	Negative	None

Table 15 shows that the pH should be between 2 and 3 in order to obtain effective precipitation, and experimentation has confirmed that this is the optimal pH range for precipitation of the maximum quantity of protein.

In addition, Foltz, Ries, and Lee (2) point out that because this precipitation involves the balancing of opposite ionic charges, an optimal ratio exists between LS and proteins in order to maximize protein removal with the least amount of LS. Experimental evidence also confirms that treatment of proteinaceous wastes with LS is quantitative, making LS dose control important.

Foltz, Ries, and Lee (2) state that while precipitating and removing the LS-protein complex, fat and fatty material (hexane soluble) are also largely removed. In wastewaters, fat is primarily particulate and emulsified with a free fatty acid content of 5 to over 50% of the total fat concentration. Wastewater acidification eliminates the strong negative charge on the free acid carboxyl groups which results in a loss of water solubility. Therefore, when the pH is between 2 and 3, most of the fat material tends to separate from the wastewater and float to the surface. Consequently, LS would not be expected to increase fat removal if protein material was not present in the wastewater. On the other hand, if protein is present and forms an insoluble complex with LS, the fat tends to be comingled with the protein-LS complex.

THE USE OF RECOVERED PROTEIN CONCENTRATE AS ANIMAL FEED

According to the Code of Federal Regulations, Title 21, Chapter 1-Food and Drug Administration,#573.600, page 553, Lignin sulfonates may be safely used in animal feeds in accordance with the following prescribed conditions:

(a) The food additive is either one, or a combination of, the ammonium, calcium, magnesium, or sodium salts of the extract of spent sulfite liquor derived from the sulfite digestion of wood or of abaca (Musa textilis) or of sisal (Agave sisalana) in either a liquid form (moisture not to exceed 50% by weight) or dry form (moisture not to exceed 6% by weight).

(b) It is used or intended for use in an amount calculated on a dry weight basis as follows:

(1) As a pelleting aid in the liquid or dry form in an amount not to exceed 4% of the finished pellets.
(2) As a binding aid in the liquid form in the flaking of feed grains in an amount not to exceed 4% of the flaked grain.
(3) As a surfactant in molasses used in feeds, as liquid lignin sulfonate, in an amount not to exceed 11% of the molasses.
(4) As a source of metabolizable energy, in the liquid or dry form, in an amount not to exceed 4% of the finished feed.

The composition of protein concentrates is dependent primarily on the sources of the raw material and components of the effluent treated. From fish and meat sources, which have been the most investigated and utilized to date, high quality components are assured because the material is dominantly muscle, blood, and fat.

Flesh particles, dissolved blood, and released fat are treated within approximately 1 to 2 hours at pH 3 so that the freshness and bacteriological condition of the raw material is excellent and superior to many other by-product animal foodstuffs. The LS concentration in the dry matter of these protein concentrates varies from 5 to 15%, but is usually about 10%. The following 3 tables show typical analyses of protein concentrates recovered from wastewaters in the fish and meat industries. Table 16 is an illustrative average analysis of herring protein concentrate which is comparable with commercial herring meal if allowance is made for the LS content.

TABLE 16. COMPARISON OF ALWATECH RECOVERED PROTEIN WITH COMMERICIAL HERRING MEAL

Component	Commercial Herring Meal, %	Alwatech Herring Protein Concentrate, %
Crude Protein	69	71
Fat	8	9
Calcium	4.8	4.7
Phosphorus	2.8	2.8
Sodium	1.4	1.6
LS	0	10
Total	86.0	99.1

Table 17 contains the analysis of a sample of material recovered by the Alwatech process at a pork slaughtering plant in Sweden.

TABLE 17. MATERIAL RECOVERED FROM A PORK SLAUGHTERING PLANT

Component	%
Protein	56.0
Oil	15.0
Fiber	2.5
Nitrogen Free Extracts	20.0
Ash	6.4
Total	99.9

Table 18 contains the results of rendering Alwatech sludge from an English poultry packing plant.

TABLE 18. RENDERED ALWATECH SLUDGE FROM AN ENGLISH POULTRY PACKING PLANT

Component	Offal and Feathers	
	without Alwatech sludge, %	with 20% Alwatech sludge, %
Fiber	0.15	0.3
Available lycine	3.3	3.37
Water	11.3	11.4
Oil	20.67	19.00
Protein	61.77	62.30
Other	2.81	3.63
Total	100.00	100.00
Cooking time, hours	6	6.3

The amino-acid composition of the protein in Alwatech protein concentrate meals has been determined for products obtained from fish and blood processing (40). It may be seen from Table 19 that the composition is unaffected by LS treatment. This would be the expected result from conventional acid precipitation of proteins extensively studied including fish, egg, soya, groundnut, and casein whose amino-acid composition is altered only by virtue of loss of certain components in the mother liquid, (i.e. non-precipitated fraction) and not by precipitation as such.

TABLE 19. AMINO ACID COMPOSITION OF CRUDE PROTEIN

Amino Acid	Fish		Blood	
	Untreated, %	LS Precipitated, %	Untreated %	LS Precipitated, %
Cystine	1.0	1.1	0.9	0.9
Aspartic acid	9.0	9.0	9.4	8.7
Methionine	3.2	3.4	2.9	2.9
Threonine	4.6	4.7	4.6	4.4
Serine	4.1	4.0	4.5	4.2
Glutamatic acid	14.1	14.5	13.6	13.2
Clycine	5.6	5.5	7.4	7.3
Alanine	6.3	6.2	6.7	6.5
Valine	5.6	5.1	5.0	4.9
Isoleucine	4.7	4.4	4.7	4.3
Leucine	6.9	6.6	7.3	7.3
Tyrocine	2.1	2.2	2.9	2.3
Phenylanine	3.6	3.8	4.0	3.9
Lysine	7.3	7.2	8.2	7.8
Histidine	2.2	2.2	2.4	2.2
Arginine	5.0	5.3	6.0	6.0
Total	85.2	85.2	90.5	86.8

Based on digestible protein (pepsin-hydrochloric acid method), the feed value of protein precipitated with lignosulphonate is only about 15 to 20% lower than that of equivalent unprecipitated blood meal. Naess (41) showed that lignosulphonates have an inhibiting effect on pepsin under acid conditions. There is no inhibiting effect in the trypsin system. Consequently, in order to determine the complete feed value, it is necessary to include the trypsin method. Protein precipitated by ordinary sulphite lye has a lower feed value than protein precipitated by alprecin.

SAFETY OF LS PRECIPITATED PROTEINS AS ANIMAL-FEED SUPPLEMENTS

Hopwood (42) reported on the safety of LS precipated proteins as animal-feed supplements. His experiments used the protein concentrate recovered by the Sterling Colorado beef-packing plant during the course of this project. In his experiment, 1 day-old broiler chicks were randomly distributed into 24 groups of 10 chicks each. Six different diets were given to 4 groups each.

Basically the diets consisted of a basal ration plus additions and substitutions. The basal ration was as follows (43):

	%
Ground corn	60.
Soybean meal (50%)	30
Meat scraps (50%)	2.5
Fish meal (60%)	2
Animal fat	2
Alfalfa meal (17%)	1
Ground limestone	0.8
Dicalcium phosphate	0.6
Salt	0.5
Vitamin premix	0.25
Other	0.2
Trace minerals	0.1
MHA or Methionine	0.05
Total	100.00

Using LS PM as an abbreviation for LS Protein Meal, the 6 diets were as follows:

Diet No.	Diet
1	Basal ration
2	Basal ration + 1 lb LS PM per ton
3	Basal ration + 5 lb LS PM per ton
4	Substitute 50 lb LS PM per ton for 50 lb/ton of soybean meal
5	Substitute 50 lb LS PM per ton for 50 lb/ton of meat scraps
6	Substitute 200 lb LS PM per ton for 50 lb/ton of meat scraps + 150 lb/ton of soybean meal

The diet and water were supplied without limit. The results of the experiment are given in Table 20. The data in this table show that the LS protein supplement had no adverse effect, and that it was an adequate substitute for both soybean meal and meat scraps. Diet 5, where LS protein supplement completely replaced meat scraps, and diet 6, where meat scraps were completely replaced and 25% of the soybean meal were replaced, showed a small improvement in 56 days.

TABLE 20. EFFECT OF LS PROTEIN SUPPLEMENT UPON CHICK GROWTH

Diet No.	% (by weight) of LS in feed	28 days		56 days		
		weight, lb	% of feed converted to weight	No.of birds remaining (40 original)	weight, lb (adjusted for sex	% of feed converted to weight
1	0	3.41	58	39	8.77	46
2	0.05	3.46	59	40	8.79	47
3	0.25	3.48	59	40	8.77	47
4	2.5	3.46	58	40	8.77	46
5	2.5	3.37	58	38	8.94	47
6	10	3.22	57	40	8.94	47
Average	--	3.40	58	39.5	8.83	47

PROTEIN QUALITY AND FEEDING TRIALS

LS is a purified derivative from wood pulping liquors which has been fed extensively to many animal species in dried form for several years. Extensive tests under controlled conditions that were reported in 1973 (44) show that relatively high concentrations of sulphite liquor concentrates in animal feed does not adversely affect feed conversion ratios.

The harmless nature of LS in rat and poultry feed has been borne out in feeding tests of protozoa, rats, and chickens to determine the protein quality and feeding value of protein concentrates. Up to 4% of crude LS as an energy source and/or pellet binder is authorized in mixed feeds, liquid feeds, and flaked grains in many countries (including the U.S.) with a wide range of feeding practices and ration formulations (45). The products contain a quantity of lignosulphonate, that implies a safe level in feed stuffs of 2.5% LS or less. This is above the anticipated inclusion rate in feeds from protein concentrates of which a relatively small tonnage would be available, compared with the quantity of other protein and energy ingredients in farm animal diets.

Provided that normal and conventional practices in the drying of protein products from industrial processes are followed, protein quality should be equivalent to that of the starting material. Indeed blood proteins, fish solubles or by-product fats, for example, probably receive longer and possibly more severe drying conditions than protein concentrates.

In the meat packing industry, the recovered material can be added to renderable material for production of meat-bone meal and tallow, or dried separately. A number of feeding trials with protein concentrates show that the feeding values of the recovered material are comparable with existing market qualities and that substitution of up to 50% in fish meal or soya bean meal feed mixture with protein concentrate does not affect live-weight gain, feed conversion ratio, or mortality.

Poultry feeding trials have been carried out as chicken growth tests (46), poultry screening tests, and pelleted feed tests. Table 21 shows a typical result obtained by three groups of 510 chicks on a diet containing 22% crude protein where the protein concentrate is substituted for herring and soyabean meal.

TABLE 21. RESULTS OF CHICK FEEDING TRIALS

Trial Result	Herring	Alwatech Protein Concentrate	
	4%	4%	8%
Mortality			
0-7 days	35	22	34
8-49 days	13	6	8
Live Weight Gain (50 days), g	1,270	1,290	1,311
Feed Conversion Ratio	2.13	2.10	2.05

Pig feeding trials have been conducted with addition of LS in amounts of 3% to 12% of the feed (47) with the protein concentrates substituted for parts or all of the soyabean meal in the diet. These pig feeding trials show that the LS concentration in feed can be up to 6% and that 50% of the soyabean meal can be replaced by protein concentrate without any significant effect on live-weight gain, feed conversion ratio, or mortality.

The suitability and nutritional adequacy of feeding lignosulphonate precipitated proteins from industrial wastewaters (Alwa-protein) as a substitute for soyabean meal was also studied in the growing pigs (48). 50% of the soyabean meal in the control ration could be replaced by Alwa-protein without any significant negative effects on weight gain, feed efficiency, or carcass quality. When Alwa-protein was fed in concentrations greater than 50%, a significantly lower weight gain, poorer carcass quality, and other negative effects on various biological systems were observed.

Blood analyses revealed some significant differences between the control group and experimental groups for the biological parameters tested. Bacteriological examination of the Alwa-protein led to the isolation of *Salmonella anatum*,indicating either inadequate sterilization procedures or recontamination during storage or transportation. Bacteriological and enzymological examinations of intestinal contents revealed no marked differences between the groups. There were no significant differences, attributable to the diets, for the various groups on macroscopic and histological examinations of different parenchymatous organs.

GENERAL DESCRIPTION OF THE ALWATECH PROCESS

The Alwatech process is a patented system for the recovery of a dry saleable proteinaceous meal from abattoir, poultry packing, and fish processing wastewaters. The process also treats these wastewaters to the point where they can be discharged into sanitary sewers. This process is based upon the specific precipitation of proteins (2) by purified, high-molecular-weight lignosulphonates (alprecin) under acid conditions. Lignosulphonates are chosen because, unlike alternative chemicals, they can precipitate dissolved blood and are accepted as animal feed additives by both the European Economic Community and the Federal Drug Administration. The lignosulphonate is derived from sulphite lye, a by-product of wood pulping. Most of the carbohydrates, another source of pollution, have been removed.

The wastewaters from abattoirs, poultry packing plants, and fish processing industries have a varying flowrate and contain suspended solids in addition to dissolved and emulsified fat and protein. For better efficiency in protein recovery, it is desirable to pretreat some wastewaters from a slaughterhouse or treat them entirely separately. An example of a wastewater requiring pretreatment is that from tripe operations. An example of a wastewater that should be treated separately is that from cattle pens. A desirable balancing tank capacity is about ½ to 1 hour's flow. A much greater balancing tank retention time would be required to extend the wastewater treatment plant operating time to 24 hours per day.

Following the balancing tank, lignosulphonic acid is added to the wastewater at a pH of about 3. The pH is reduced with sulphuric acid. Following this precipitation step, the floc containing protein, fat, and suspended material is separated by dissolved air flotation. Following this step, the effluent is neutralized to $6 \leq \text{pH} \leq 8$ with calcium hydroxide or sodium hydroxide and then discharged to the sanitary sewer.

For a screened wastewater with an initial BOD in the range of 1,000 to 2,500 mg/l, this process usually produces an effluent of the following quality: 70 to 80% BOD reduction, <300 mg/l suspended solids, and <75 mg/l fat. The solids concentration of the sludge produced by the flotation process is usually 6 to 12%, depending on the origin and pretreatment of the wastewater. This sludge is neutralized with calcium hydroxide.

Following neutralization, the sludge is processed through a coagulator to a filter belt or centrifuge (decanter) for additional reduction of moisture content. Depending on which device is used, the resulting sludge will contain between 30 and 50% solids. The water removed from the sludge in the filter belt or centrifuge operation may contain as much as 40% of the lignosulphonate originally added, and lignosulphonate recirculation can economically reduce this chemical consumption. The concentrated (30 to 50% solids) sludge can be dried in a rendering plant, mixed with other byproducts, or dried in a separate drier.

ALWATECH PROCESS PILOT PLANT RESULTS

A pilot plant study was carried out at the Monfort Packing Plant in Greeley, Colorado, in June and July of 1972 to demonstrate the Alwatech process results. These results were obtained using 2 parallel sedimentation basins (20 minute detention time) with top skimmers and bottom scrapers. The Alwatech process utilizes a modified dissolved air flotation to obtain a high solids concentration sludge.

Table 22 contains the results of this pilot plant operation. Two important things can be gleaned from this table:

(1) A direct comparison of the performance of dissolved air flotation with the Alwatech process, and
(2) When used with the last page of Table 32, a direct comparison of pilot plant and full-scale performance.

A comparison of the 2 pilot plant results indicate that the Alwatech process is significantly better than the dissolved air flotation process alone in every parameter measured. In fact, the Alwatech process is so much better that it appears the 2 processes are no more comparable than say an activated sludge process and a primary settling tank.

It will be noted that in the full-scale process, the COD concentration in the influent was 2.2 times that in the pilot plant influent, grease and oil was double, organic N was more than double, and suspended solids were 3.2 times as concentrated in the full-scale plant influent, compared to the pilot plant influent. Still the various % removals (with the exception of phosphate) were about 90% of the %

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TABLE 22. COMPARISON OF PILOT PLANT AND FULL-SCALE PLANT PERFORMANCE

			Dissolved Air Flotation Pilot Plant		Alwatech Pilot Plant		Alwatech Full-Scale Plant	
			in	out	in	out	in	out
$\frac{me}{\ell}$	pH3 alkalinity						19.4	9.3
	pH7 acidity						-7.3	2.3
wastewater temperature, °F							101	97
mg/ℓ chloride							523	439
umhos/cm at 25°C							4,687	5,073
pH at 25°C			6.68	6.85	6.86	2.92	6.97	3.83
pH after LSA+H_2SO_4							2.56	
gal/hr			1,288		1,175		44,152	
$\frac{\text{mg/}\ell\text{ LSA}}{\text{mg/}\ell\text{ COD in}}$			0		0.112		0.0977	
mg/ℓ	LSA		0		238		388	
	H_2SO_4		0		591		1,106	
	base		0		316 (NaOH)		560 ($Ca(OH)_2$)	
			in	%	in	%	in	%
mg/ℓ	COD		2,280	39	2,123	79	4,607	71
	20°C BOD		1,065	42	1,045	81	2,945	71
	grease and oil		424	51	382	96	570	82
Phosphate, mg/ℓ P			37	21	24	25	17	49
$\frac{mg}{\ell}$ N	ammonia N						82	41
	organic N		65	20	60	70	128	63
Solids	total, mg/ℓ	total					5,535	12
		volatile					2,335	63
	suspended, mg/ℓ	total	828	60	770	90	2,462	78
		volatile					1,695	83
	settleable, mℓ/ℓ						8	82

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removals obtained in the pilot plant. For example, in the pilot plant, the COD removed was 79%, and the %COD removal in the full-scale plant was 71% which is 0.9 x 79%.

SECTION 5

DESCRIPTION OF THE STERLING COLORADO BEEF COMPANY MEAT PACKING OPERATION

Cattle from feedlots are slaughtered and the carcass is shipped the following day to other plants for additional processing. Figure 3 is a flow chart for the Sterling Colorado Beef Company packinghouse. The rest of this section will describe the elements of this flow chart.

CATTLE PENS

The capacity of the cattle pens is 1,200 head (23 ft^2 per head). There is a 1 ft high curb around the perimeter, and the concrete floors slope toward a center drain trench that runs the full length of the cattle pens. Cattle pen wastewater is collected in a sump and pumped across a 20 mesh shaker screen. Solids from this screen go into a hopper. Wastewater from this screen is discharged into two 15,000 gallon cone bottom tanks connected in series so that the settleable solids can be removed. The solids from these two conical bottom tanks are hauled with the screen solids to farm land where they are used for fertilizer and land fill. The wastewater from these two conical bottom tanks is mixed with the Alwatech plant effluent throughout the work day. Beginning February 5, 1979, reclaimed wastewater from the Alwatech wastewater treatment plant was used for the rendering condensers and cattle pen cleanup.

SLAUGHTERING DEPARTMENT

The slaughtering department occupies an area of 12,400 ft^2 and has a capacity of 248 cattle per hour. It is a restrained stunning system using on-the-rail conveyor dressing. The total length of the work line is 811 feet:

Operation	Length, Feet
bleeding conveyor	176
skinning conveyor	255
hide down puller	20
head cut-off	60
eviscerating and splitting	105
trim and inspection	80
shrouding	115

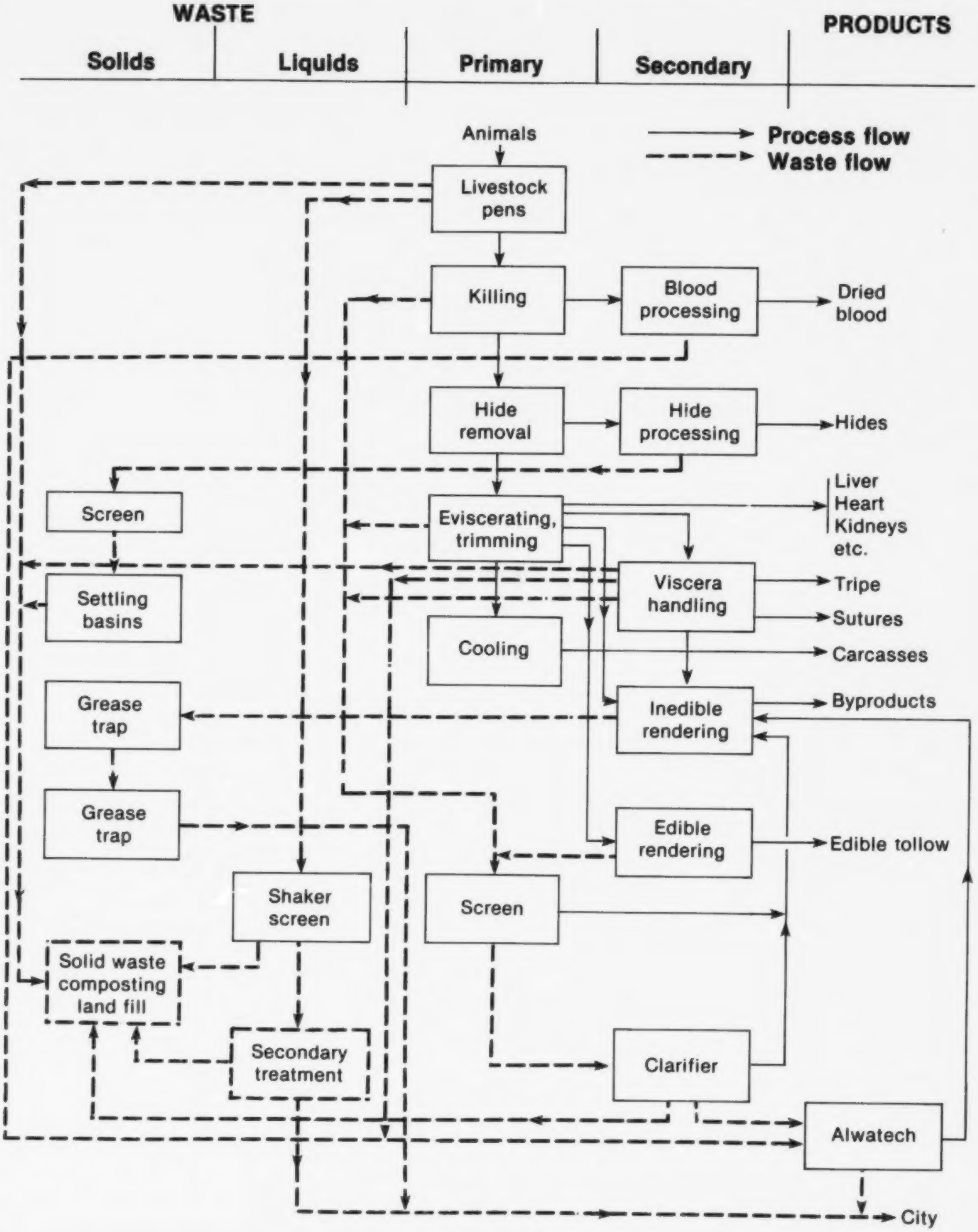
WASTE
Solids
Liquids
Primary
Secondary
PRODUCTS
Animals
Process flow
Waste flow
Livestock pens
Killing
Blood processing
Dried blood
Hide removal
Hide processing
Hides
Eviscerating, trimming
Liver
Heart
Kidneys
etc.
Screen
Settling basins
Viscera handling
Tripe
Sutures
Cooling
Carcasses
Grease trap
Inedible rendering
Byproducts
Grease trap
Edible rendering
Edible tollow
Shaker screen
Screen
Solid waste composting land fill
Secondary treatment
Clarifier
Alwatech
City

Figure 3.
Flow chart for the Sterling Colorado Beef Company packinghouse.

BLOOD PROCESSING

Blood has the highest BOD of any liquid waste emanating from meat processing, an ultimate (about 20-day) BOD of 405,000 mg/l (49). The 5-day BOD (BOD_5) ranges from 150,000 to 200,000 mg/l. Cattle contain about 49 pounds of blood, so there is about 10 pounds of BOD_5 per animal slaughtered compared with 0.2 pounds of BOD_5 excreted per person per day. Clotted blood is about 70% of the total and has an ultimate BOD of about 470,000 mg/l, while the ultimate BOD of the liquid part is about 200,000 mg/l (49). In comparison, the ultimate BOD of domestic sewage is only about 300 mg/l.

Blood is collected in the following curbed areas: sticking, bleeding, skinning, hide down puller, and head cut-off. Blood flows to a central pit where it is pumped to storage tanks. The floor and walls of the curbed bleeding area that discharges to the blood tank are cleaned with a minimum of water (the blood is squeegeed to the blood tank). The water used in the first rinse is discharged to the blood tank and evaporated.

From these storage tanks the blood is pumped through an in-line steam coagulator which discharges to a shaker screen. The coagulated blood is then augered to a gas fired rotary drum dryer. Dried blood meal is then conveyed to storage outside.

Stick water from the shaker screen is mixed with the water from the tripe operation and pumped to the cone settling tank in the Alwatech building for processing.

HIDE REMOVAL AND PROCESSING

The hide house area is 23,000 ft^2. Hides are conveyed from the kill floor to a dump truck which dumps them into 1 of four raceways for curing (80 to 100 hides per dump truck load). One day's production fills 2 of the 4 raceways. After 1 day in the raceways, the hides are pulled, trimmed (trimmings are sent to inedible rendering), passed through a squeezer, inspected, bundled and tied, and placed on pallets for shipping.

Brine water squeezed from the hides and raceway overflows flow across a screen to remove hair and manure which is conveyed by an auger to containers for land fill disposal. The brine water passing through the screen is pumped to one of three settling basins. Each of these three settling basins is 55 ft long, 9.5 ft wide, and 4 ft deep.

The bottoms of these 3 settling basins slope to the deepest point so that the settled solids can be removed by a front end loader after the supernatant brine has been pumped away.

The brine water enters these 3 settling basins at the deepest end and overflows at the other (shallowest) end into a flume which empties into an

18 ft x 12 ft x 6 ft sump. The brine water overflow from this sump flows to a 35 ft x 18 ft x 6 ft lixator where fresh salt is added to increase the brine water salinity. From the lixator, the brine water is pumped to the aforementioned raceways as needed. Excess water from the hides is hauled to landfill. Otherwise, the hide house has a closed liquid system. All overflows from the raceways, sumps, and process floors drain to the 3 settling basins. Consequently, there is no discharge from the hide operation to any of the wastewater streams, although roughly 2 gallons of water per hide are hauled to landfill.

VISCERA HANDLING

Offal items are frozen and shipped in truck or railroad car quantities. Manual washing of meal and offal products have press-to-open sprays. Pressures and flow rates are controlled with pipe restrictions and locked valves.

PAUNCH MANURE AND TRIPE

After inspection, the paunch and intestines are separated. Paunch manure is dry dumped for recovery of tripe. The paunch is conveyed to a moving top table where it is hung by hooks from an overhead cable conveyor. The paunch is cut open over a screw conveyor and the paunch manure is discharged to a mechanical screen, with the resulting liquid flowing to the Alwatech wastewater treatment plant. This liquid contains a large fraction (<60%) of the BOD from the paunch waste solids. Paunch solids are about 90% water, and about 50 to 60 pounds are produced per animal. The paunch solids have a first-stage BOD of over 100,000 mg/l (the 5-day BOD is about 40% of the first-stage BOD), and 85% of this BOD is soluble in water.

The overhead cable conveyor then carries the paunch to a dumping station where it is opened and flushed out. The paunch then passes through an automatic wash cabinet. The resulting liquid and contents from the paunch are moved by a screw conveyor to a 20 x 20 mesh shaker screen for dewatering. Then the dewatered material from the paunch is conveyed to a storage hopper. As soon as the hopper contains a truck load, it is dumped into a truck and hauled to surrounding farms where it is utilized as fertilizer. The flushing water passing through the shaker screen flows to a 20 x 20 mesh rotating screen and after passing through this last screen it flows to the Alwatech wastewater treatment plant.

The washed paunches are transferred from the cable conveyor to revolving washers for scalding. Depending on size, 80 to 100 paunches are processed at a time. Detergents are added to the hot water in order to remove the superficial surface of the mucous membrane. Usually a series of 3 washes and 3 rinses are required. A fourth rinse is used to cool the tripe before it is removed from the revolving washers. After cooling, the tripe is removed and inspected. Then it is conveyed to another department where it is packed and then placed in a sharp freeze before going to the storage freezer.

The wash and rinse waters from the paunch scalding operation flow to a 1,000 gallon tank equipped with a propeller type agitator. These waters are subsequently pumped from the 1,000 gallon tank to a model 2500 rotostrainer (with a 0.2 screen opening) where a large quantity of the fat and suspended solids are removed and conveyed to the rendering department. After passing through the rotostrainer, these waters are combined with the stick water from the blood coagulating operation (described above) and pumped to the Alwatech building for treatment in the Alwatech wastewater treatment plant.

INEDIBLE RENDERING

Inedible rendering is by conventional batch type cookers using barometric condensers. This condenser water contains low concentrations of fat and protein and the BOD concentration is usually less than the BOD in the Alwatech effluent. Consequently, this condenser water is discharged directly to the biological wastewater treatment plant. Beginning February 5, 1979, reclaimed wastewater from the Alwatech plant was used for cooling these rendering condensers.

EDIBLE TALLOW

Edible tallow is rendered by the low temperature centrifuge process.

WATER CONSERVATION

Water conservation is an essential part of this inplant wastewater control program. Packing plants using the most water per animal generate the most waste per animal. Excessive washing, especially with hot water, removes juices and tissues from the product and carries them into the wastewater stream. As this plant illustrates, water use can be reduced at many locations.

WATER RECYCLE AND BLOWDOWN WATER

Water in refrigeration condensers and compressor cooling jacket water is either reused in plant processes or recycled through heat exchanging devices (evaporative condensers).

DESCRIPTION OF THE ALWATECH PROCESS INSTALLED AT THE STERLING COLORADO BEEF COMPANY PLANT

Alwatech Plant Design Criteria

The Alwatech Wastewater Treatment/Protein Recovery Plant installed at the Sterling Colorado Beef Company was designed to treat up to 800,000 gallons per day of wastewater at a maximum rate to 52,000 gallons per hour.

The plant was designed for average influent concentrations of 1,800 mg/l BOD, 900 mg/l of oil and grease, and 1,000 mg/l of suspended solids.

The design objectives included at least 70% removal of the BOD, a suspended solids concentration in the effluent of $<$300 mg/l, $<$75 mg/l of oil and grease in the effluent, and recovery of about 880 pounds per hour of dry solids from sludge with a moisture concentration of 60 to 70%. This concentrated sludge was to be dried using existing rendering facilities.

An existing 90,000 gallon clarifier (with bottom scraper and grease skimming device) was intended to be used as an equalizing basin. The overflow from this clarifier was to be pumped to the wastewater treatment plant. All wastewater was to be screened before entering the clarifier.

Figure 4 shows the protein recovery plant layout. The existing clarifier is shown in the upper left hand corner of the drawing. The second story of the 2 story portion of the plant is shown by dashed lines.

Figure 5 is a photograph of the east side of the building housing this plant (the photograph was taken before the installation of the acid storage tank and the $Ca(OH)_2$ silo).

Figure 5. East side of protein recovery plant building.

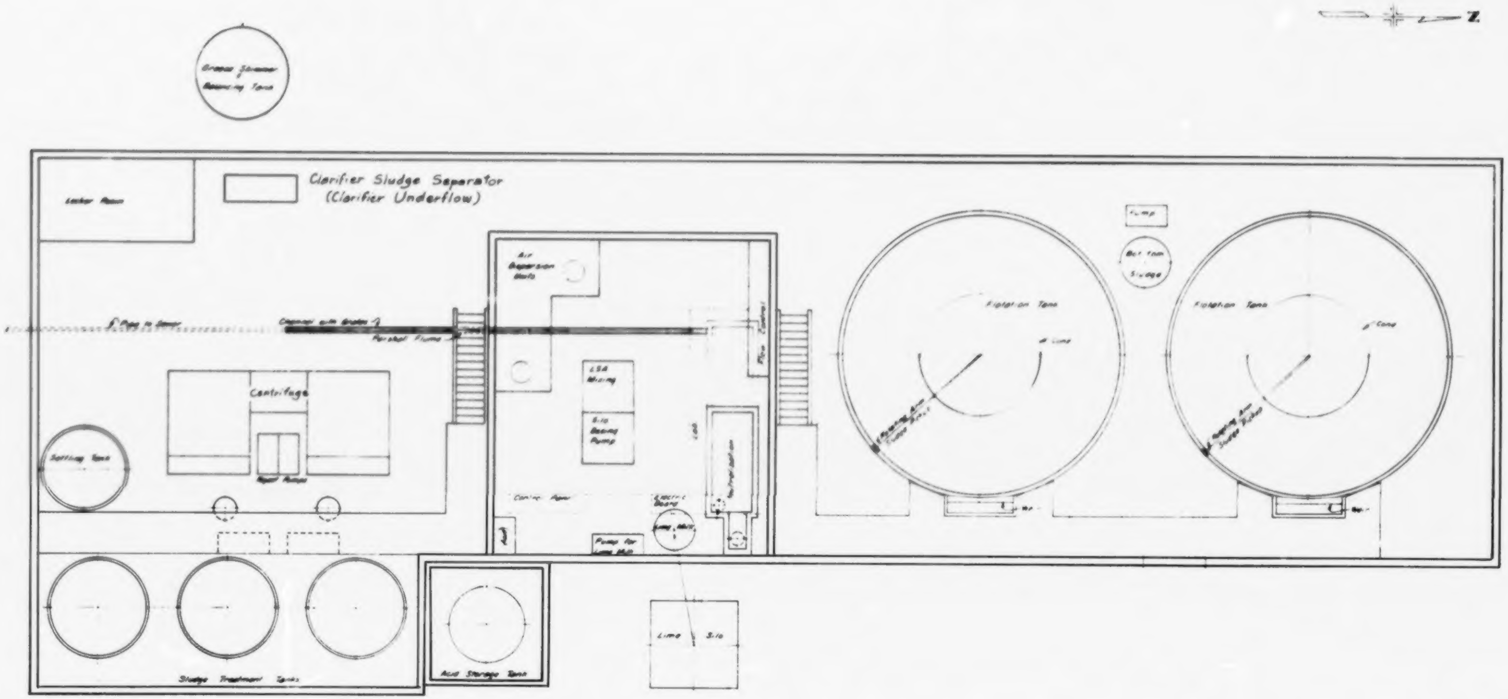
Grease Skimmer Balancing Tank
Locker Room
Clarifier Sludge Separator
(Clarifier Underflow)
Pipe to Sewer
Channel with Grates
Parshall Flume
Centrifuge
Settling Tank
Sludge Treatment Tanks
Acid Storage Tank
Air Separation Units
LSA Mixing
Silo Bearing Pump
Control Room
Electric Board
Pump for Lime Mix
Flow Control
Lime Silo
Pump
Bottom Sludge
Flotation Tank
Flotation Tank
Cone
Cone
Z

FIGURE 4.
STERLING COLORADO BEEF COMPANY
ALWATECH PLANT LAYOUT

Pretreatment of Wastewater

Wastewater from the slaughtering operations is screened and discharged to a balancing tank. Overflow from the balancing tank goes to the Alwatech wastewater treatment plant. Floating grease and fat are removed from the surface of the balancing tank (formerly a clarifier prior to the construction of the Alwatech plant) and pumped to the rendering plant.

Early in this project, the settled solids from the balancing tank were mixed with the sludge from the Alwatech plant, but this was found to be unsatisfactory, so the settled sludge from the balancing tank is now hauled to a landfill operation. These solids are primarily sand and paunch manure (paunch manure disposal was discussed in Section 4). The volume of these settled solids from the balancing tank average about 1,300 gallons per day.

Wastewater from the balancing tank is pumped to the Alwatech plant. During the day, the liquid level in the balancing tank is kept about 15 to 30 cm below the overflow weir, and this level is reduced an additional 2.5 meters at the end of the day. Wastewater from the slaughterhouse refills this balancing tank during the night.

At one time, the tripe wash and rinse water was inadequately screened, and a significant quantity of solids were lost by settling in the balancing tank. Consequently, a rotostrainer was installed and these solids are now transferred directly to rendering. However, the water phase still contains some fine settleable material. Stick water from the blood coagulation operation also contains some fine solids that pass through the shaker screen. Instead of letting these solids be lost with the settled sludge from the clarifier, stick water and tripe water are mixed and pumped to a small conical bottom settling tank. The recovered solids are pumped to the Alwatech sludge treatment tanks while the liquid phase is mixed with water pumped from the clarifier.

For maximum protein recovery and maximum nitrogen removal, it is important to minimize the biological activity in the wastewater prior to treatment in the Alwatech plant. Consequently, it was decided to bypass the livestock pen wash water around the Alwatech plant. The quantity and strength of this wash water is given in Table 35. Later the barometric condenser wastewater was also bypassed around the Alwatech plant. The quantity and strength of this wastewater is also given in Table 35. Bypassing the barometric condenser water reduced the temperature of the wastewater in the balancing tank about 20°F. Both of these measures have reduced the biological activity in the balancing tank.

Process Flow Diagram

Figure 6 is the process flow diagram of the Alwatech wastewater treatment/protein recovery plant. Solids settled out in the balancing tank are

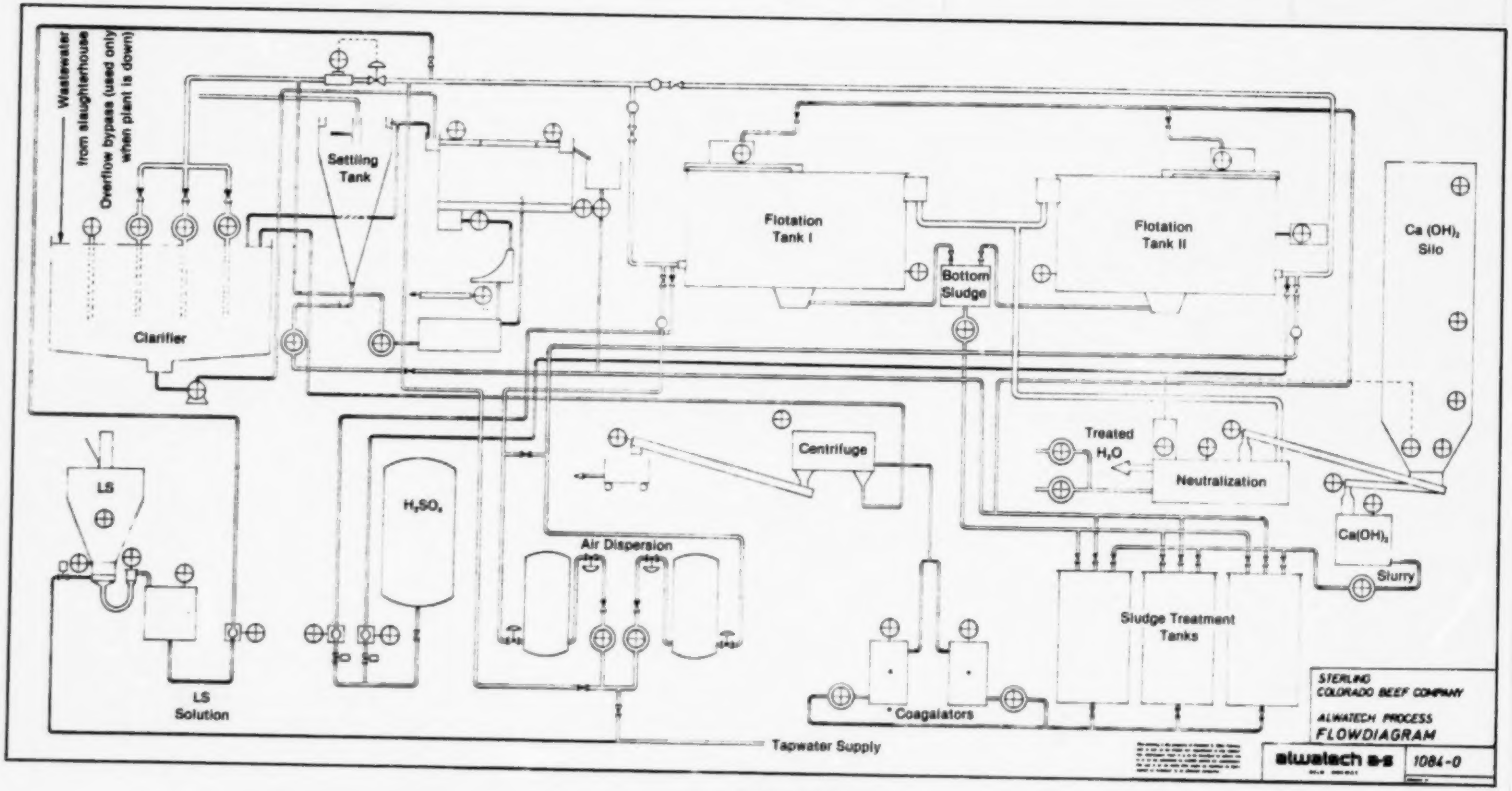
Wastewater from slaughterhouse
Overflow bypass (used only when plant is down)
Settling Tank
Clarifier
Flotation Tank I
Flotation Tank II
Bottom Sludge
Ca (OH)₂ Silo
Treated H₂O
Neutralization
Centrifuge
Ca(OH)₂
Slurry
H₂SO₄
LS
LS Solution
Air Dispersion
Sludge Treatment Tanks
Coagalators
Tapwater Supply
STERLING COLORADO BEEF COMPANY
ALWATECH PROCESS
FLOWDIAGRAM
alwatech a-s
1084-0

Figure 6.
Sterling Colorado Beef Company Alwatech Process
Flow Diagram

continuously pumped by a bottom sludge pump to a rectangular skim tank. This tank is equipped with top and bottom scraper arrangements. Some of the material settled in the balancing tank will float in the skim tank. This floating material is skimmed off and hauled to landfill by truck. Solids settled in the skim tank are pumped over a Bauer screen and the residue is also hauled to landfill.

The liquid overflow from the skim tank is pumped and mixed with the wastewater pumped from the balancing tank to flotation tanks I and II shown in Figure 7. LS, H_2SO_4, and water (partially saturated with air) are added to this wastewater just before it enters the flotation tanks.

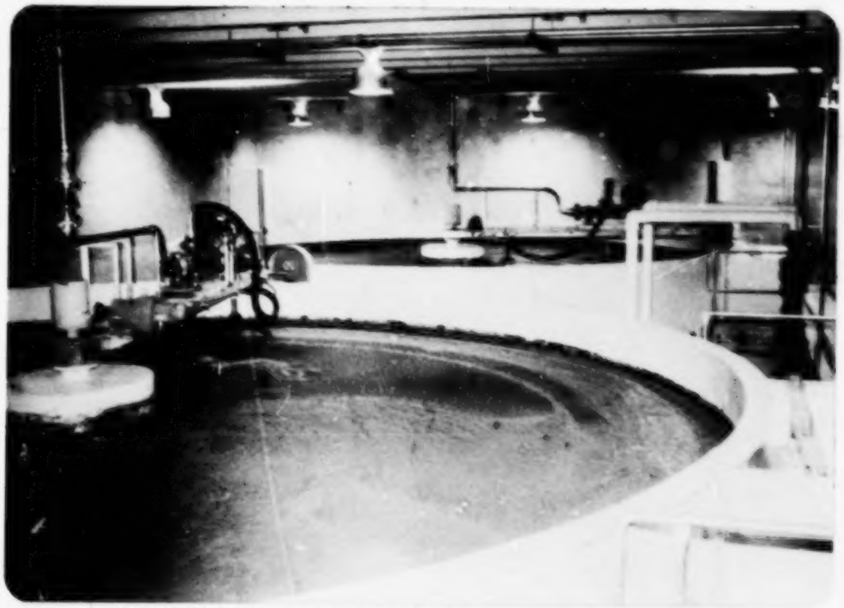

Figure 7. Flotation Tanks I and II.

LS, a powder, is dissolved in water to give a 10% solution. A dosing pump (controlled from the control panel) delivers the required quantity of LS solution. H_2SO_4 is diluted with water before being added to the wastewater. H_2SO_4 is pumped from its storage tank by acid dosing pumps that are automatically controlled by pH control equipment with ultrasonically cleaned electrodes. Each flotation tank has independent pH control. Wastewater partially saturated with air is produced by high pressure pumps, injectors, and pressure vessels.

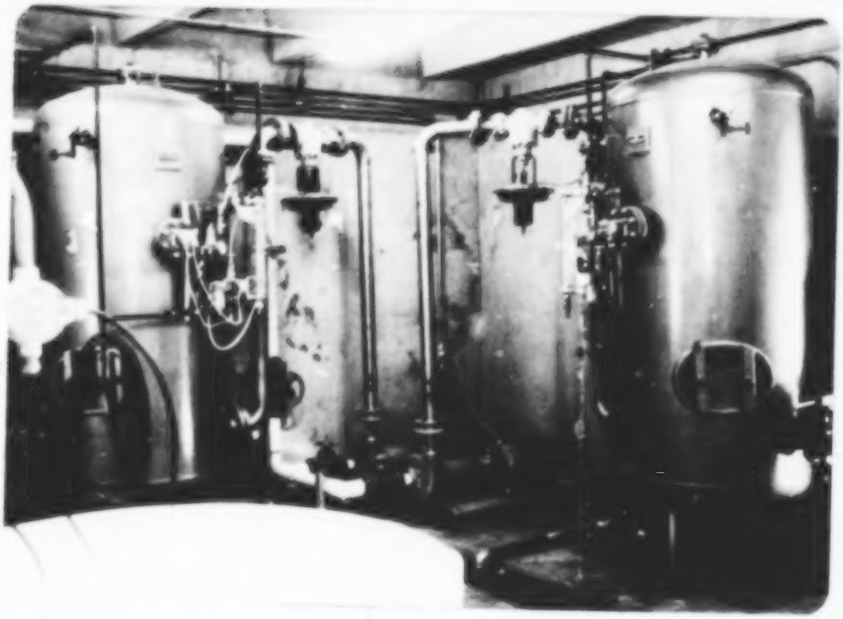

Figure 8. Air Pressurization Tanks and Associated Equipment

Overflow from the flotation tanks is neutralized with $Ca(OH)_2$ dosed by a screw (in the $Ca(OH)_2$ silo) which is controlled by pH equipment. The $Ca(OH)_2$ mixing and neutralization tanks are shown in Figure 9.

The protein sludge is removed from the surface of the 2 flotation tanks and pumped by scraper pumps to the 3 sludge treatment tanks. Bottom sludge is removed from the flotation tanks by bottom scrapers and pumped to the 3 sludge treatment tanks by a bottom sludge pump.

Tripe wash and rinse water mixed with stick water from blood coagulation is pumped from the slaughterhouse to the cone settling tank. The liquid phase is pumped via the skim tank into the feed line to the Alwatech plant. Settled solids are pumped to the sludge treatment tanks.

When a sludge treatment tank is full, its contents are neutralized with $Ca(OH)_2$. Sludge pumps pump the neutralized protein sludge to one of the 2 coagulators where steam is added with slow stirring. The heat coagulated sludge is dewatered by a centrifuge (Sharples P3400) to a 44% solids concentration. During the course of this project it was demonstrated that a centrifuge will give a lower moisture concentration in the dewatered sludge than filterbelts.

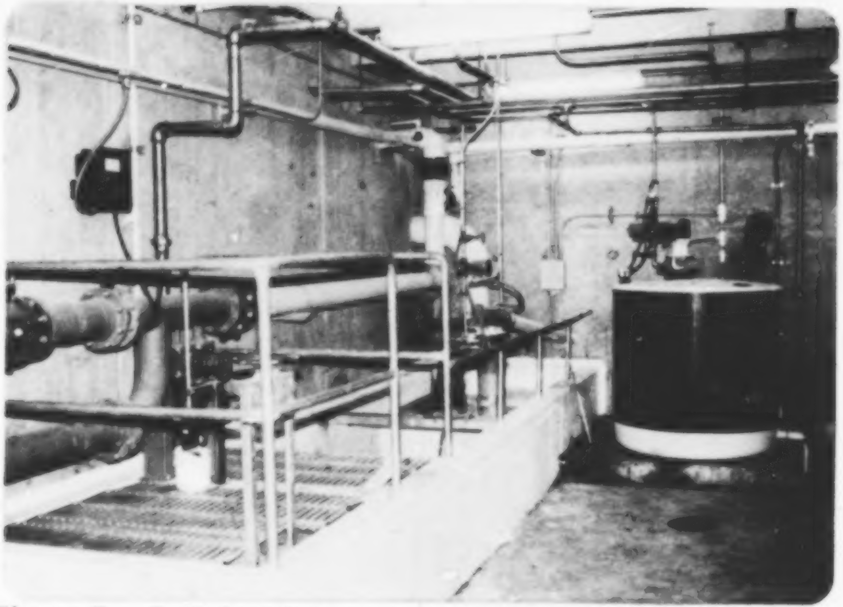

Figure 9. $Ca(OH)_2$ Mixing and Effluent Neutralization Tanks

The concentrated sludge is augered to a mobile container, weighed, and dried the next day in a rotary type, direct fired blood drier. The liquid separated from the sludge by the centrifuge flows by gravity back to the balancing tank and consequently is recycled to the Alwatech wastewater treatment plant. The process shown in Figure 6 is controlled from a central panel containing automatic equipment and other instrumentation.

This central panel is shown in Figure 10.

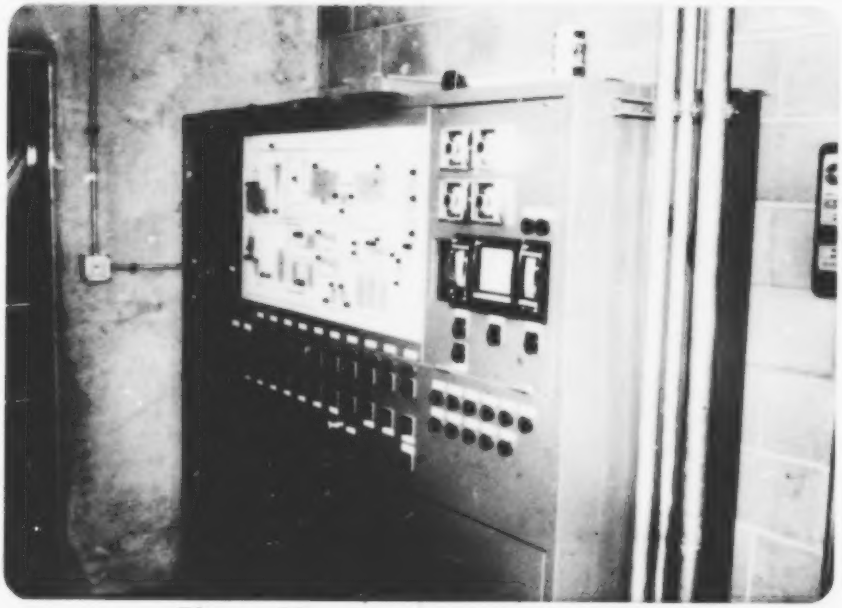

Figure 10. Process Control Panel

SECTION 6

OBSERVED DATA SUMMARIES

Because of practical space limitations, only a small fraction of the comprehensive data observed during the course of this project is briefly summarized in this section. Nevertheless, it is believed that this brief summary does give an adequate representation of the performance of this process with respect to beef packing wastewater effluent. While the organization of this section is an attempt to present this brief summary in logical order, this has not been entirely successful because of the comprehensive nature of this project.

MAINTENANCE

Table 23 lists the maintenance required, corresponding man-hours, maintenance frequency, and total man-hours required per year. At a cost of $7.50 per man-hour, this represents a cost of $5,715 per year for about 95 man-days (roughly 4.3 man-months per year).

REPAIRS

Table 24 lists the repairs made during the one year interval from 1-25-78 to 2-5-79. Total repair costs are as follows:

	$/Hr	Hours	$
Material (total from Table 24)			1,885.49
Outside contractor (12-20-78, Table 24)			2,324.08
Millwright labor	7.50	67.5	506.25
Electrician labor	7.70	9.25	71.23
Subtotal (from Table 24 total)		76.75	$4,787.05

Total cost of repairs and maintenance came to ($5,715 + $4,787 =) $10,502 per year or about $200 per week.

OPERATING LOG SUMMARY

Because the interpretation of the observed data will sometimes depend on how the plant was operated, an operating log summary is given in Table 25. All of the data reported in this Section 6 was observed during the interval July 5, 1978 - February 22, 1979 (about 7 months). Some unsatisfactory

TABLE 23. MAINTENANCE

		Time required, man-hours	Frequency				Man-hours per year if plant is operated 365 days per year
			Daily	Weekly	Monthly	6 months	
Sludge Side	1. Remove back plates from both flow indicators. Clean out any build-up.				✓		
	2. Take down and flush the line from the coagulator to the sharples centrifuge.	2					24
	Remove top of coagulators and check steam injector lines. Remove any solids from bottoms.	8				✓	16
Alwatech System	1. Clean the strainer and Rotometer LS dosing unit.		✓				
	2. Blow solids from bottoms of both air dispersion units.						
	3. Clean pH electrodes and store in clean water:						
	i. Flotation Tank I						
	ii. Flotation Tank II						
	iii. Water Neutralization Basin						
	4. Clean level electrodes in lime slurry tank.	0.75					274
	5. Service the sharples centrifuge	0.75	✓				274

TABLE 23. MAINTENANCE (CONTINUED)

Alwatech Water Side	1. Check all pump belt drives and packing glands. 2. Clean air pressure reducers on air dispersion units. 3. Check all pH meters with buffer solution. 4. Service air slide gate on LS feeder. 5. Check acid system for leaks.	1.5		✓			78
	1. Clean LS solution tank and level electrodes 2. Flush out suction and discharge valves on LS dosing pump. 3. Air dispersion tanks: i. Disassemble both flow control valves, clean out fat build-up, etc. ii. Open both units and clean out fat build-up, etc. iii. Disassemble both air lines and both air injectors and clean. 4. Drain water neutralization basin, remove all solids, sand, etc. 5. Remove the back plates from all flow indicators and remove all build-up. 6. Clean the level electrodes in the sludge pump tank.	8			✓		96
	Total man-hours per year						762

TABLE 24. ANNUAL REPAIR COSTS

Date			Repair	Material cost, $	Labor man-hours
M	D	Y			
1	25	78	Replaced belt on pump serving cone settling tank (piece of horn in pump).	3.36	0.25
2	4	78	Replaced 2 off-on switches on main control panel (contacts stuck).	26.90	1.5
2	6	78	Replaced ball check valves in acid dosing pump (flat spot on balls).	60.00	1
			Replaced bearing in sharples centrifuge drive motor	16.35	4
2	13	78	Replaced belts on 2 pumps; incoming water from clarifier (discharge line from pumps frozen because electrical power was off overnight).	14.24	2
2	25	78	Replaced belt on pump serving cone settling tank (bones, etc. in pump).	3.36	0.25
3	4	78	Replaced pump membrane of acid dosing pump (leaking).	175.00	2
3	13	78	Replaced suction hose on pump serving flotation tank (suction nozzle plugged so hose collapsed).	26.00	1
3	28	78	Replaced 90° ell and coupling and 15 feet of 3" PVC pipe (line from air dispersion unit to flotation tank). Hand valve on air dispersion unit was opened too fast, causing water hammer.	28.30	3
4	21	78	Replaced drive coupling on drive for lime dosing screw from lime silo to water neutralization basin (screen plugged).	6.00	0.75
5	4	78	Replaced suction hose on pump serving flotation tank (hole in hose).	26.00	1
5	5	78	Replaced motor on acid dosing pump (1 phase burned out).	202.00	1
5	8	78	Replaced drive coupling on drive for lime dosing screw from lime silo to lime slurry tanks (screw plugged).	6.00	0.5

TABLE 24. ANNUAL REPAIR COSTS (CONTINUED)

Date			Repair	Material cost, $	Labor man-hours
M	D	Y			
5	12	78	Replaced acid lines to both flotation tanks (dilution water line plugged, so heat from acid caused lines to sag).	15.50	1.5
6	17	78	Replaced plunger shaft seals in LS dosing pump.	20.00	1
7	10	78	Replaced O-ring seals and pump membranes in acid dosing pump.	188.00	1.5
7	17	78	Replaced output shaft and piston in carter drive unit serving coagulator 2.	210.00	16
9	22	78	Replaced bearings in sharples centrifuge	272.23	16
11	9	78	Replaced drive shaft in gear box of drive unit (lime dosing screw from lime silo to water neutralization basin plugged).	58.00	1.5
11	10	78	Replaced check valve disc on pump serving incoming water from clarifier (locking nut missing).	3.60	0.75
11	13	78	Replaced stator on pump serving flotation tank (suction nozzle plugged).	143.75	2
11	17	78	Replaced drive shaft in gear box drive unit (lime dosing screw from lime silo to water neutralization basin). Screw plugged.	63.00	1.5
12	14	78	Replaced motor on LS dosing pump (2 phases burned out).	72.70	1.25
12	20	78	Replaced drive units and screws (from lime silo to water neutralization basin and lime slurry tank). Increased size of screws and drive units. Outside contractor $2,324.08.		
1	2	79	Replaced motor on LS mixer (2 phases burned out).	65.20	1.5
1	8	79	Replaced output shaft and piston in carter drive unit of LS pump.	180.00	14
			Totals	1,885.49	76.75

TABLE 25. OPERATING LOG SUMMARY

Period covered by this report.		July 5, 1978 -- February 22, 1979
Unsatisfactory effluent data (for purposes of analysis)		August 12-26, 1978 September 8-12, 1978
2 Week Trial Periods	Unsatisfactory (See Table 26)	July 24, 1978 -- August 4, 1978
	Satisfactory (See Table 27)	October 17-30, 1978
	Satisfactory (See Table 28)	February 9-22, 1979
Rendering condenser water bypassed around the Alwatech Wastewater Treatment Plant.		August 29, 1978 -- February 22, 1979
Centrifuge Reject Water	To landfill	October 16-30, 1978
	To influent clarifier	October 31, 1978 -- November 5, 1978 November 13, 1978 -- February 22,1979
	To cone tank	November 6-12, 1978
Reclaimed water from the Alwatech Wastewater Treatment Plant used for the rendering condensers and cattle pen cleanup.		January 22-23, 1979 February 5-22, 1979
Alwatech plant operated using zero mg/l calcium lignosulfonate		February 5, 1979
Sludge to landfill.		January 2-4, 1979 January 18-19, 1979 January 22-26, 1979
LS dosed manually.		January 3-5, 1979 January 8-29, 1979

effluent data was obtained during a period when the bottom sludge removal device in one of the flotation tanks malfunctioned (unsatisfactory for purposes of analysis).

There were 3 two-week trial periods: The first was unsatisfactory and the last two were satisfactory. Satisfactory performance during the trial period consisted of satisfying the criteria given in Table 26. Actual performance during the second 2 week trial period is given in Table 27. Comparison of Tables 26 and 27 shows that the actual performance considerably exceeded the performance guarantee except for the suspended solids effluent concentration which was an average of only 2 observations (only 2 influent concentrations were < 1,500 mg/l).

Comparing the results of the third 2 week trial period given in Table 28 with Table 26 shows that the actual system performance considerably exceeded the performance guarantee in every respect. The actual results in Tables 27 and 28 are about the same (81% BOD removal, etc.) except for suspended solids which was 6% greater in the latter table. In summary, the plant is capable of removing 81% of the BOD, 83 to 89% of the suspended solids, and 94% of the fat on the average.

TABLE 26. ALWATECH A/S PERFORMANCE GUARANTEE FOR THE STERLING COLORADO BEEF COMPANY WASTEWATER TREATMENT PLANT*

Water quality parameter (1)	Influent concentration, mg/l (2)	Effluent (% removal or concentration) (3)
BOD	0-1,450	< 360 mg/l
	1,450-2,500	70% removal
Suspended Solids	0-1,500	< 300 mg/l
	over 1,500	80% removal
Fat	0-500	<75 mg/l
	over 500	85% removal

*This performance guarantee was subject to conditions that included a maximum of 52,000 U.S. gallons per hour in any one hour.

TABLE 27. ACTUAL ALWATECH A/S PERFORMANCE FOR THE SECOND 2 WEEK TRIAL PERIOD*

Water quality parameter	Influent concentration, mg/l	Effluent (% removal or concentration)
BOD	1,450-2,500	81% removal
	over 2,500	
Suspended Solids	0-1,500	453 mg/l
	over 1,500	85% removal
Fat	0-500	19 mg/l
	over 500	94% removal

*Actual flow rate through the plant averaged 43,392 U.S. gallons per hour (the maximum flow rate observed was 48,000 gallons per hour on October 17, 1978).

TABLE 28. ALWATECH A/S PERFORMANCE FOR THE THIRD 2 WEEK TRAIL PERIOD*

Water quality parameter	Influent concentration, mg/l	Effluent (% removal or concentration)
BOD	1,450-2,500	75% removal
	over 2,500	82% removal
Suspended Solids	over 1,500	89% removal
Fat	0-500	20 mg/l
	over 500	94% removal

*Actual flow rate through the plant averaged 47,390 U.S. gallons per hour (the maximum flow rate observed was 50,400 gallons per hour on February 14, 1979).

WEEKLY PLANT OPERATING SUMMARY

Table 29 shows some of the quantities produced and consumed by the wastewater treatment plant as well as some of the operating characteristics and conditions. Explanations of each column are as follows:

Column	
1	month: days included. Example July 5-9 would be 7:5-9
2	Gallons of sludge produced per 1,000 gallons treated
3	lb $Ca(OH)_2$ used for sludge neutralization per 1,000 gallons of sludge dewatered
4	lb steam used per 1,000 gallons of wastewater treated
5	kwhr of electricity used per 1,000 gallons of wastewater treated
6	ft^3 of air (at 100 psi) used per 1,000 gallons of wastewater treated

Column	
7	gallons of hot water used per 1,000 gallons of wastewater treated
8	pH of wastewater after addition of LS and H_2SO_4
9	pH of neutralized sludge
10	outside air temperature at noon, °F

Analysis of the plant performance has shown that the optimum pH of the wastewater after addition of Calcium Lignosulfonate and H_2SO_4 (actual pH values are given in column 8) is 2.5, but process results are not seriously adversely affected at pH values as high as 2.8, so for all practical purposes, $2.5 < pH < 2.8$ will probably give almost the same results. This indicates that one should try for a pH of about 2.65 ± 0.15. The plant was operated at an average pH of 2.6 and within the pH range of 2.6 ± 0.14 about 2/3 of the time, so that for the most part, the plant was operated at the pH that would have been desired for maximum performance.

The mean of column 2 of Table 29 shows that about 2.7% of the influent to the wastewater treatment plant ends up as liquid sludge. About 65 lb of $Ca(OH)_2$ are required per 1,000 gallons of sludge in order to neutralize the sludge. This means that the quantity of $Ca(OH)_2$ required for this purpose averages 1.72 lb $Ca(OH)_2$ per 1,000 gallons treated or 206 mg/l. From column 9, the average pH of the neutralized sludge was observed to be 9.1 ± 0.4.

Steam was supplied at a pressure of 60 psig and at a temperature of 305°F, so that its total energy content was about 1,181 Btu/lb. Assuming that the boiler makeup water has a temperature of about 110°F, the energy added is about (1,181-78 =) 1,103 Btu/lb. Consequently, steam consumption of 32 lb per 1,000 gallons treated is roughly equivalent to 35,300 Btu per 1,000 gallons treated.

The fossil fuel equivalent of one Btu of electricity is 4 Btu because the efficiency of electricity generation and transmission averages about 25%. Therefore, an electrical energy consumption of 3.5 kwhr per 1,000 gallons treated is equivalent to a fossil fuel consumption of (3.5x3,412x4 =) 47,800 Btu per 1,000 gallons treated. At a cost of 2.25¢ per kwhr, the cost of electricity was 7.9¢ per 1,000 gallons of wastewater treated.

Air compressor efficiencies are about 80% (50), and the theoretical power requirements of compressors are

$$P = 0.22\,Q \left[(p/14.7)^{0.283} - 1 \right] \qquad (8)$$

where P = theoretical horsepower
Q = ft^3/min of free air compressed from atmospheric pressure (14.7 psia) to a working pressure of p psia
p = working pressure, psia

TABLE 29. WEEKLY PLANT OPERATING SUMMARY

1978 Week (1)	gal sludge / 1,000 gal (2)	lb $Ca(OH)_2$ / 1,000 gal sludge (3)	lb steam / 1,000 gal treated (4)	kwhr / 1,000 gal treated (5)	ft^3 air / 1,000 gal treated (6)	gal hot H_2O* / 1,000 gal treated (7)	pH after LS and H_2SO_4 (8)	pH of neutralized sludge (9)	outside air at noon °F (10)
7:5-9	25.0	73.8	15.9	2.60	5.88	0.49	2.7	9.5	92
7:10-14	28.2	84.4	23.4	3.03	6.45	3.22	2.63	9.63	92
7:17-22	23.3	53.3	15.8	2.76	8.47	2.31	2.70	9.6	85
7:24-29	22.9	107.7	22.3	2.57	4.79	2.37	2.68	9.64	99
7:31-8:5	29.1	60.8	48.3	2.84	4.30	2.59	2.66	9.14	73
8:7-12	30.3	55.9	38.6	2.82	4.40	2.25	2.51	9.33	92
8:14-18	29.0	53.3	34.0	2.40	2.52	1.70	2.69	9.49	86
8:21-25	26.5	52.4	34.4	2.06	2.72	0.77	2.53	9.52	91
8:28-31	32.4			2.16	0.96	1.11	2.42		80
9:5-9	17.3		0	2.65	1.71	5.98	2.63		89
9:11-16	35.2	49.0	26.8	2.97	3.21	9.47	2.425	9.52	78
9:18-22	29.6	51.9	47.7	2.90	4.11	3.36	2.24	9.89	54
9:25-30	30.1	48.2	51.0	2.55	3.32	4.58	2.50	8.8	77
10:2-7	30.4	43.5	45.2	3.06	2.30	2.36	2.54	8.7	62
10:9-14	13.4	46.8	48.8	3.05	5.64	2.76	2.67	8.9	72
10:16-21	22.8	43.0	42.3	2.71	4.48	10.6	2.59	8.58	66
10:23-28	29.2	73.4	42.5	2.90	4.84	7.59	2.68	8.9	54
10:30-31 11:1-5	27.1	60.8	42.7	2.75	4.87	9.72	2.7	8.6	62
11:6-10	28.0	40.3	3.71	2.42	5.38	8.87	2.7	8.9	53
11:13-17	29.2	59.1	35.8	4.05	6.82	2.45	2.75	8.8	40
11:20-25	26.2	64.0	45.7	5.91	2.34	0.74	2.7	9.3	36
11:27-30 12:1-2	30.4	68.2	38.2	3.71	2.44	1.15	2.55	9.1	38

TABLE 29. WEEKLY PLANT OPERATING SUMMARY (Continued)

1978/ 1979 Week (1)	$\frac{\text{gal sludge}}{\text{1,000 gal}}$ (2)	$\frac{\text{lb Ca(OH)}_2}{\text{1,000 gal sludge}}$ (3)	$\frac{\text{lb steam}}{\text{1,000 gal treated}}$ (4)	$\frac{\text{kwhr}}{\text{1,000 gal treated}}$ (5)	$\frac{\text{ft}^3\text{ air}}{\text{1,000 gal treated}}$ (6)	$\frac{\text{gal hot H}_2\text{O*}}{\text{1,000 gal treated}}$ (7)	pH after LS and H_2SO_4 (8)	pH of neutralized sludge (9)	outside air at noon °F (10)
12:4-8	23.2	72.3	32.0	3.99	1.97	12.7	2.7	9.3	22
12:11-15	27.0	79.2	36.8	3.18	4.55	2.86	2.6	8.7	35
12:18-22	24.6	86.6	27.8	3.45	2.18	1.07	2.6	8.9	36
12:26-29	20.7	67.0	24.8	3.08	6.13	3.93	2.7	9.2	26
1:2-6	28.8	51.7	31.8	6.67	6.83	7.09	2.7	8.5	17
1:8-12	19.1	103.9	24.1	7.32	7.01	2.61	2.7	9.5	21
1:15-19	20.8	82.1	19.7	3.38	2.97	1.53	2.8	9.5	35
1:22-26			2.0	7.27	2.15	1.31	2.7		26
1:29-31 2:1-2	33.3	73.6	34.6	6.12	2.64	1.61	2.6	9.2	14
2:5-9	33.0	47.7	38.2	3.62	6.72	4.02	2.2	9.2	26
2:12-17	29.5	81.9	44.9	3.11	4.09	3.78	2.45	9.1	36
2:19-23	23.7	64.0	36.6	2.75	10.23	2.79	2.45	8	46
Mean	26.6	64.5	32.0	3.49	4.39	3.87	2.60	9.1	
SD	4.8	17.2	13.6	1.42	2.12	3.20	0.14	0.4	
SD/Mean	0.18	0.27	0.43	0.41	0.48	0.83	0.053	0.046	

* Hot water is used for cleaning purposes only.

Because Sterling, Colorado is at an elevation of 3,935 feet, atmospheric pressure there is only 12.7 psia. Therefore, for application to Sterling, equation 8 should probably be rewritten as

$$P = 0.22Q\left[(p/12.7)^{0.283} - 1\right] \qquad (9)$$

The pressure of the air reported in column 6 of Table 29 is 100 psig= 112.7 psia=p. Therefore the theoretical power requirement at Sterling is

$$P = 0.22\,Q\left[(112.7/12.7)^{0.283} - 1\right] = 0.188\,Q \text{ hp},$$

and the actual power requirement is $0.188Q/0.8 = 0.235\,Q$ hp. From column 6 of Table 29, the average amount of air used was 4.39 ft^3/1,000 gallons treated. From Table 32, the average flow rate through the plant was 44.152 thousand gallons per hour, so (4.39)(44.152) = 194 ft^3 of air was used per hour or 3.23 ft^3 per minute. Therefore, the actual power requirement was (0.235)(3.23) = 0.76 hp. The corresponding energy requirement is 0.56 kwhr per hour. Consequently, the unit energy requirement is

$$\frac{0.56 \text{ kwhr}}{\text{hour}}\,\bigg|\,\frac{\text{hour}}{194 \text{ ft}^3} = 0.0029 \text{ kwhr/ft}^3.$$

From column 6 of Table 39, the average quantity of air required was 4.4 ft^3 per 1,000 gallons of wastewater treated, so the electrical energy required was

$$\frac{0.0029 \text{ kwhr}}{\text{ft}^3}\,\bigg|\,\frac{4.4 \text{ ft}^3}{10^3 \text{ gallons}} = 0.013 \text{ kwhr per 1,000 gallons treated},$$

a quantity completely negligible in comparison to the other electrical energy requirements.

The temperature of the hot water makeup averages 110°F and the temperature of the hot water furnished averages 140°F, so the average energy added is 30 Btu per lb. From column 7 of Table 29, about 3.9 gallons of hot water are used per 1,000 gallons of wastewater treated, so (3.9x8.34x30 =) 976 Btu are consumed in the form of hot water per 1,000 gallons treated (hot water is used for cleaning purposes only).

In summary, the total fossil fuel equivalent energy consumption is:

	Btu/10^3 gallons
Steam	35,300
Electricity	47,800
Hot Water	1,000
Total	84,100

Assuming that the cost of natural gas is \$1.84 per million Btu, then the energy cost for steam and hot water is ($36{,}300 \times 1.84 \times 10^{-6}$ =) 6.7¢ per 10^3

gallons. Consequently, total 1979 energy costs were (6.7+7.9 =) 14.6¢ per 1,000 gallons of wastewater treated.

Average weekly outside air temperatures (at noon) varied from 14 to 99°F during the course of this project. However, this variation does not appear to have had a consistent significant effect on any of the other quantities in Table 29.

WATER USE

Table 30 shows the weekly water use and the 3 major categories of water use. Beginning February 5, 1979, reclaimed water from the Alwatech wastewater treatment plant was used for the rendering condensers and cattle pen cleanup, thereby reducing the quantity of water used for those purposes from 67 to 30 gallons per head of cattle killed.

Before February 5, 1979, about 80% of the wastewater produced was treated in the Alwatech plant. Of the remaining 20%, about 4% was used to wash the cattle pens and about 16% was used in the rendering condensers. After February 5, 1979, about 91% of the water used was treated in the Alwatech plant. Of the remaining 9%, about 1% was used to wash the cattle pens, and about 8% was used in the rendering condensers.

RENDERING CONDENSER WASTEWATER QUALITY

Four analyses of the water from the rendering condensers were made on four different dates and these results are given in Table 31. It will be noted that while the BOD is relatively constant, both the grease and oil, and total suspended solids concentrations are quite variable.

Also given in Table 31 are the average values for BOD, grease and oil, and total suspended solids observed in the Alwatech Plant effluent. It will be noted that, with the single exception of grease and oil (where the 2 values are not significantly different), the water from the rendering condensers is of higher quality than the Alwatech wastewater treatment plant effluent, and this is the reason that beginning August 29, 1978, the rendering condenser water was bypassed around the Alwatech Wastewater Treatment Plant.

BOD CONCENTRATION VERSUS TIME

Analyses of the Alwatech plant influent gave the following results:

Days	% of Ultimate 20°C BOD
0	0
1	34.9
2	67.5
3	78.2
4	83.7
5	87.7
∞	100.0

TABLE 30. UNIT WATER USE

	Week		Gallons of Water per Head of Cattle Killed			
Month (1)	Days (2)	Year (3)	Water Bypassing Alwatech Plant		Treated In Alwatech Plant (6)	Total (Col. 4 + + Col. 5 + + Col. 6) (7)
			Cattle Pens (4)	Rendering Condensers (5)		
September	5-9	78	17	49	233	299
September	11-16	78	16	28	238	282
September	18-22	78	15	62	212	289
September	25-30	78	17	78	284	379
October	2-7	78	19	65	230	314
October	9-14	78	15	56	226	297
October	16-21	78	13	54	317	384
October	23-28	78	13	110	318	441
October November	30-31 1-5	78	17	51	323	391
November	6-10	78	14	41	316	371
November	13-17	78	21	56	348	425
November December	27-30 1-2	78	12	49	341	402
December	4-8	78	15	52	327	394
December	11-15	78	18	44	242	304
December	18-22	78	16	51	332	399
December	26-29	78	12	48	319	379
January	2-6	79	5	48	240	293
January	8-12	79	7	42	265	314
January	15-19	79	16	52	221	289
January	22-26	79	4	38	184	226
January February	29-31 1-2	79	9	39	274	322
Mean			14	53	276	343
SD			4	17	50	58
SD/Mean			0.32	0.32	0.18	0.17

TABLE 30. UNIT WATER USE (Continued)

			Gallons of Water per Head of Cattle Killed			
Week			Water Used in Addition to Alwatech Plant Effluent		Treated in Alwatech Plant (6)	Total (Col. 4 + + Col. 5 + + Col. 6) (7)
Month (1)	Days (2)	Year (3)	Cattle Pens (4)	Rendering Condensers (5)		
February	5-9	79	2	23	317	342
February	12-16	79	3	21	319	343
February	19-23	79	1	40	326	367
Mean			2	28	321	351
Standard Deviation (SD)			1	10	5	14
SD/Mean			0.5	0.36	0.02	0.04

TABLE 31. ANALYSES of Water from the Rendering Condensers

1978 (1)	5-day, 20°C BOD, mg/l (2)	Grease and Oil, mg/l (3)	Total Suspended Solids, mg/l (4)
8-21	412	130	117
8-30	432	59	255
9-5	414	222	471
9-7	432	39	656
Average	422	112	375
Standard Deviation	11	83	237
Coefficient of Variation	0.026	0.74	0.63
Alwatech Wastewater Treatment Plant Effluent (Average)	854	103	542

On the other hand, the 5-day, 20°C BOD, represented only about 64% of the COD, and even the ultimate 20° C BOD represents only about 73% of the COD.

WASTEWATER TREATMENT PLANT RESULTS

The Alwatech Wastewater Treatment Plant results are shown in Table 32 (21 pages). The values on the last page of this table are statistical parameters calculated from the data on the preceeding 20 pages representing up to 78 observations each. On some dates the results from only one of the 2 flotation tanks are shown. The word "in" represents the Alwatech plant influent and the word "out" represents the Alwatech plant effluent. The "%" column represents % removal.

Values reported for pH 3 alkalinity are the me/l of acid required to reduce the sample pH to 3. In a similar fashion the values reported for pH 7 acidity are the me/l of acid (-) or base (+) required to change the sample pH to 7.

Values reported for the row entitled "pH after $LS+H_2SO_4$" are the pH values resulting after the required amounts of calcium lignosulfonate and sulfuric acid were added. The row entitled

$$\text{"}\frac{\text{mg/l LS}}{\text{mg/l COD in}}\text{"}$$

is the ratio of the mg/l of calcium lignosulfonate added to the mg/l of COD in the plant influent. The 3 rows entitled "mg/l LS", "mg/l H_2SO_4", and "mg/l $Ca(OH)_2$" represent respectively the mg/l of calcium lignosulfonate and sulfuric acid added to the plant influent and the mg/l of calcium hydroxide added to the plant effluent to obtain the pH values reported for the plant effluent.

On the last page of Table 32 are the average, standard deviations (SD), and coefficients of variation (SD/average) of the wastewater treatment plant results. The pH 3 alkalinity was reduced about 10 me/l while the pH 7 acidity was increased almost the same amount. On the average, the wastewater temperature dropped only about 4°F while passing through the wastewater treatment plant. The specific conductance was increased about 8% by the chemicals added.

The influent pH averaged 7 and the effluent pH averaged about 3 pH units less. While the average effluent pH (3.8) seems low, by the time it combines with the wastewater that bypasses the Alwatech Plant, the resulting pH discharged to the sewage treatment plant is 7.

On the average, the plant was operated at about 85% of its maximum design capacity during the hours it was in operation.

Table 32. Wastewater Treatment Plant Results		DATE	7-6-78		7-11-78		7-13-78		7-18-78 Tank I	
			in	out	in	out	in	out	in	out
$\frac{me}{\ell}$	pH3 alkalinity		21.5	9.5	20.4	9.5	14.7	7.5		
	pH7 acidity		-6.7	-0.4	-9.8	-1.9	-4.1	0.8		
wastewater temperature, °F			106	104	104	108	101	103	108	106
mg/ℓ chloride										
µmhos/cm at 25°C										
pH at 25°C			7.21	4.1	7.43	3.8	7.39	3.95	7	3.96
pH after LS $+H_2SO_4$			2.5		2.63		2.7		2.66	
gal/hr			40,400		43,200		42,000		22,600	
$\frac{mg/\ell\ LS}{mg/\ell\ COD\ in}$			0.0727		0.0896		0.0839		0.0793	
mg/ℓ	LS		331		290		330		346	
	H_2SO_4		1,225		1,107		1,119		1,192	
	$Ca(OH)_2$		389		416		846		500	
			in	%	in	%	in	%	in	%
mg/ℓ	COD		4,550	57	3,237	68	3,934	78	4,365	78
	5-day, 20°C BOD		2,850	65	2,620	65	2,500	69	2,662	70
	grease and oil		1,034	91	683	86	419	83		
Phosphate, mg/ℓP										
$\frac{mg}{\ell}$ N	ammonia N				36.7	18	32.5	16		
	organic N									
Solids	total, mg/ℓ	total	7,496	33	6,032	20	5,784	12		
		volatile								
	suspended, mg/ℓ	total	3,540	83	2,260	79	1,980	77	1,590	93
		volatile								
	settleable, mℓ/ℓ		27	93	14	71	7.5	93		

Table 32. Wastewater Treatment Plant Results (continued)

DATE			7-19-78 Tank I		7-24-78		7-25-78		7-26-78	
			in	out	in	out	in	out	in	out
me/ℓ	pH3 alkalinity									
	pH7 acidity									
wastewater temperature, °F			105	107	108	99	117	108	115	107
mg/ℓ chloride										
μmhos/cm at 25°C										
pH at 25°C			6.96	4	7.3	3.91	6.84	4	6.57	3.97
pH after LS +H_2SO_4			2.62		2.9		2.6		2.6	
gal/hr			22,500		22,100		22,800		22,400	
mg/ℓ LS / mg/ℓ COD in			0.0762		0.0968		0.0749		0.1018	
mg/ℓ	LS		259		306		314		281	
	H_2SO_4		831		1,167		1,265		1,557	
	$Ca(OH)_2$		536		388		513		454	
			in	%	in	%	in	%	in	%
mg/ℓ	COD		3,397	61	3,160	74.5	4,190	74.5	2,760	
	5-day, 20°C BOD		1,852	62	1,790	70.9	2,640	70.1	1,900	61.1
	grease and oil				650	93.4	690	96.1	335	89.9
Phosphate, mg/ℓP										
mg/ℓ N	ammonia N									
	organic N									
Solids	total, mg/ℓ	total								
		volatile								
	suspended, mg/ℓ	total	1,220	81	1,580	78.5	2,240	89.7	1,280	86.7
		volatile								
	settleable, mℓ/ℓ									

Table 32. Wastewater Treatment Plant Results (continued)

		DATE	7-27-78		7-28-78		7-31-78		8-1-78	
			in	out	in	out	in	out	in	out
$\frac{me}{\ell}$	pH3 alkalinity									
	pH7 acidity									
wastewater temperature, °F			112	108	118	109	104	92	107	103
mg/ℓ chloride										
μmhos/cm at 25°C										
pH at 25°C			6.69	3.98	6.84	3.97	6.86	4.1	6.91	4.07
pH after LS +H_2SO_4			2.65		2.6		3.69		2.61	
gal/hr			22,600		23,250		20,800		22,200	
$\frac{\text{mg}/\ell\ \text{LS}}{\text{mg}/\ell\ \text{COD in}}$			0.0723		0.1845		0.0960		0.0906	
mg/ℓ	LS		264		310		338		328	
	H_2SO_4		1,085		1,044		1,201		1,200	
	$Ca(OH)_2$		484		382		370		653	
			in	%	in	%	in	%	in	%
mg/ℓ	COD		3,650	55.1	1,680	47.3	3,520	77.8	3,620	75.0
	5-day, 20°C BOD		2,000	55.5	2,400	68.3	2,200	72.7	2,700	78.5
	grease and oil		510	85.9	445	89.7	480	95.8	265	91.3
Phosphate, mg/ℓP										
$\frac{mg}{\ell}$ N	ammonia N									
	organic N									
Solids	total, mg/ℓ	total								
		volatile								
	suspended, mg/ℓ	total	1,820	81.3	1,300	93.1	1,680	88.7	1,500	77.3
		volatile								
	settleable, mℓ/ℓ									

Table 32. **Wastewater** Treatment Plant Results (Continued)

		DATE	8-2-78		8-3-78		8-4-78		8-30-78 Tank I	
			in	out	in	out	in	out	in	out
me/ℓ	pH3 alkalinity								20.8	7.42
	pH7 acidity								-8.56	1.14
wastewater temperature, °F			107	108	100	104	101	101	95	99
mg/ℓ chloride										
μmhos/cm at 25°C										
pH at 25°C			6.63	3.97	6.55	3.77	6.52	3.73	7.0	3.73
pH after LS +H_2SO_4			2.78		2.68		2.55		2.3	
gal/hr			22,200		22,200		22,600		29,200	
mg/ℓ LS			0.0904		0.1161		0.1092		0.1908	
mg/ℓ COD in										
mg/ℓ	LS		375		511		510		522	
	H_2SO_4		1,252		1,176		1,109			
	$Ca(OH)_2$		575		420		239		424	
			in	%	in	%	in	%	in	%
mg/ℓ	COD		4,150	76.1	4,400	81.4	4,670	80.1	2,736	65
	5-day, 20°C BOD		3,000	78.7	3,400	82.1	3,400	81.8	2,775	76
	grease and oil		615	93.8	960	96.8	845	96.7	419	93
Phosphate, mg/ℓP										
mg/ℓ N	ammonia N									
	organic N									
Solids	total, mg/ℓ	total							5,620	14
		volatile							2,588	66
	suspended, mg/ℓ	total	1,600	86.9	2,500	92.0	2,920	86.0		
		volatile								
	settleable, mℓ/ℓ								12	92

Table 32. Wastewater Treatment Plant Results (Continued)

		DATE	9-5-78 Tank I		9-7-78 Tank I		9-13-78 Tank I		9-15-78	
			in	out	in	out	in	out	in	out
$\frac{me}{\ell}$	pH3 alkalinity		19.7	7.7	19.4	6.8			22.84	
	pH7 acidity		-8.56		-7.16	1.4				17.5
wastewater temperature, °F			96	88	98	97	99	98	101	101
mg/ℓ chloride										
μmhos/cm at 25°C			5,750	4,900	4,500	5,000	4,400	5,100	4,000	5,550
pH at 25°C			7.0	3.8	7.0	3.8	7.0	2.9	7.0	2.6
pH after LS +H_2SO_4			1.86		2.31		1.95		2.615	
gal/hr			26,000		26,000		26,000		40,400	
$\frac{\text{mg/}\ell\text{ LS}}{\text{mg/}\ell\text{ COD in}}$			0.1847		0.1297		0.1016		0.0983	
mg/ℓ	LS		510		468		390		325	
	H_2SO_4		1,327		1,006		1,230		1,283	
	$Ca(OH)_2$		442		362		281		467	
			in	%	in	%	in	%	in	%
mg/ℓ	COD		2,761	53	3,608	67	3,840	79	3,306	58
	5-day, 20°C BOD		3,270	45	2,205	67				
	grease and oil		633	74			653	62	150	88
Phosphate, mg/ℓP										
$\frac{mg}{\ell}$ N	ammonia N									
	organic N									
Solids	total, mg/ℓ	total	6,468	8	5,284	14	6,120	23	5,732	23
		volatile	3,416	39	2,168	59	2,968	62	2,728	60
	suspended, mg/ℓ	total	1,830	19	1,250	86	2,260	89	2,740	88
		volatile			100		2,000		300	
	settleable, mℓ/ℓ		25	[illegible]	3	95	15	87	9.0	89

Table 32. Wastewater Treatment Plant Results (Continued)		DATE	9-19-78 Tank I		9-21-78 Tank I		9-26-78		9-28-78 Tank I	
			in	out	in	out	in	out	in	out
$\frac{me}{\ell}$	pH3 alkalinity		22.2		19.6		21.1	13.0	19.8	10.62
	pH7 acidity		-5 7	11.0	-7.64	10.44	-8.4	-3.0	-7.2	-1.4
wastewater temperature, °F			110	102	105	106	105	101	107	105
mg/ℓ chloride			580	399	680	570	750	490	1,000	540
μmhos/cm at 25°C			4,400	5,100	4,100	4,900	4,900	5,750	4,500	5,600
pH at 25°C			7 1	2.9	7.2	3.0	7.2	3.69	7.0	3.74
pH after LS +H_2SO_4			2.11		1.98		2.535		2.4	
gal/hr			26,000		26,000		46,800		26,000	
mg/ℓ LS			0.1294		0.1529		0.0915		0.0913	
mg/ℓ COD in										
mg/ℓ	LS		482		459		306		386	
	H_2SO_4		1,278		1,066		1,392		1,314	
	$Ca(OH)_2$		316		321		723		589	
			in	%	in	%	in	%	in	%
mg/ℓ	COD		3,724	59	3,002	61	3,346	65	4,229	74
	5-day, 20°C BOD									
	grease and oil		347	99	200	44	271	94	158	74
Phosphate, mg/ℓP										
$\frac{mg}{\ell}$ N	ammonia N		45.3	22	55.5	14	52	37		
	organic N		38	3	60.0	17	65	37		
Solids	total, mg/ℓ	total	5,804	23	5,256	15	5,936	5	5,788	3
		volatile	2,680	61	2,140	52	2,620	64	2,460	65
	suspended, mg/ℓ	total	1,870	93	1,210	87	1,680	80	1,190	53
		volatile	1,470	91	1,030	86	1,340	89	1,120	76
	settleable, mℓ/ℓ		1.5	93	2	95	6	42	2.5	60

Table 32. Wastewater Treatment Plant Results (Continued)		DATE	10-2-78 Tank II		10-4-78 Tank II		10-6-78 Tank II		10-10-78 Tank I	
			in	out	in	out	in	out	in	out
me/ℓ	pH3 alkalinity		14.9	11.6	17.3	10.6	19.2	10.0	18.2	7.6
	pH7 acidity		-7.4	-5.9	-8.2	0.16	-6.3	1.0	-6.0	2.0
wastewater temperature, °F			100	93	111	109	110	107	111	100
mg/ℓ chloride									830	650
µmhos/cm at 25°C			3,800	4,750	4,400	5,200	4,250	5,000	4,100	4,750
pH at 25°C			7.6	3.8	7.1	3.8	7.3	3.8	6.7	5.1
pH after LS +H_2SO_4			2.4		2.55		2.6		2.6	
gal/hr			29,400		28,000		28,000		21,500	
mg/ℓ LS / mg/ℓ COD in			0.1392		0.1265		0.1090		0.1281	
mg/ℓ	LS		335		373		381		433	
	H_2SO_4		928		1,178		1,176		1,178	
	$Ca(OH)_2$		730		561		510		722	
			in	%	in	%	in	%	in	%
mg/ℓ	COD		2,406	77	2,949	55	3,494	63	3,379	61
	5-day, 20°C BOD		1,280	60	1,850	66	1,880	64	2,400	66
	grease and oil		663	35	185	96	200	94	410	90
Phosphate, mg/ℓP										
mg/ℓ N	ammonia N								70	34
	organic N								20	57
Solids	total, mg/ℓ	total	4,568		5,164	1	5,116	1	5,368	4
		volatile	1,676	54	2,132	60	2,048	53	2,268	57
	suspended, mg/ℓ	total	660	12	965	83	1,440	84	1,480	83
		volatile	600	75	910	89	1,120	90	1,240	86
	settleable, mℓ/ℓ		1.5		1.5	67	2.5	80	4.5	96

Table 32. Wastewater Treatment Plant Results (Continued)		DATE	10-17-78		10-18-78		10-19-78		10-20-78	
			in	out	in	out	in	out	in	out
me/ℓ	pH3 alkalinity									
	pH7 acidity									
wastewater temperature, °F			102	97	107	101	104	106	100	100
mg/ℓ chloride										
μmhos/cm at 25°C										
pH at 25°C			6.96	3.8	7.21	3.8	7.13	3.8	7.14	3.8
pH after LS +H_2SO_4			2.56		2.6		2.54		2.6	
gal/hr			48,000		40,000		40,600		45,400	
mg/ℓ LS / mg/ℓ COD in			0.0898		0.1271		0.1429		0.1168	
mg/ℓ	LS		395		534		643		438	
	H_2SO_4		1,154		1,509		1,319		799	
	$Ca(OH)_2$		773		1,009		917		631	
			in	%	in	%	in	%	in	%
mg/ℓ	COD		4,400	85	4,200	79	4,500	84	3,750	85
	5-day, 20°C BOD		2,600	80	2,700	77	2,800	79	2,400	85
	grease and oil		530	91	440	92	510	94	115	99
Phosphate, mg/ℓP										
mg/ℓ N	ammonia N									
	organic N									
Solids	total, mg/ℓ	total								
		volatile								
	suspended, mg/ℓ	total	2,000	78	1,200	52	2,320	75	1,540	88
		volatile								
	settleable, mℓ/ℓ									

Table 32. Wastewater Treatment Plant Results (Contined)

		DATE	10-23-78		10-24-78		10-25-78		10-26-78	
			in	out	in	out	in	out	in	out
me/ℓ	pH3 alkalinity									
	pH7 acidity									
wastewater temperature, °F			97	90	99	97	97	96	97	96
mg/ℓ chloride										
µmhos/cm at 25°C										
pH at 25°C			7.57	3.74	7.3	3.8	7.36	3.8	7.9	3.8
pH after LS + H_2SO_4			2.61		2.75		2.75		2.6	
gal/hr			46,400		43,400		42,400		45,600	
mg/ℓ LS / mg/ℓ COD in			0.1190		0.1273		0.1273		0.1203	
mg/ℓ	LS		351		420		504		497	
	H_2SO_4		1,140		978		897		974	
	$Ca(OH)_2$		477		532		473		434	
			in	%	in	%	in	%	in	%
mg/ℓ	COD		2,950	73	3,300	79	3,960	88	4,130	84
	5-day, 20°C BOD		1,850	77	2,700	85	2,180	87	2,650	82
	grease and oil		330	97	425	92	510	97	410	98
Phosphate, mg/ℓP										
mg/ℓ N	ammonia N									
	organic N									
Solids	total, mg/ℓ	total								
		volatile								
	suspended, mg/ℓ	total	1,320	75	1,560	81	2,200	84	1,700	88
		volatile								
	settleable, mℓ/ℓ									

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Table 32. Wastewater Treatment Plant Results (Continued)

DATE			10-27-78		10-30-78		11-6-78		11-8-78	
			in	out	in	out	in	out	in	out
me/ℓ	pH3 alkalinity									
	pH7 acidity									
wastewater temperature, °F			98	95	97	85	94	81	99	95
mg/ℓ chloride										
µmhos/cm at 25°C										
pH at 25°C			7.34	3.8	7.2	3.8	6.8	3.7	6.8	3.8
pH after LS +H_2SO_4			2.7		2.65		2.65		2.75	
gal/hr			45,600		46,000		44,400		44,000	
mg/ℓ LS / mg/ℓ COD in			0.1329		0.1247		0.0855		0.0889	
mg/ℓ	LS		509		434		436		489	
	H_2SO_4		918		829		1,028		1,036	
	$Ca(OH)_2$		451		449		560		600	
			in	%	in	%	in	%	in	%
mg/ℓ	COD		3,830	84	3,480	77	5,100	87	5,500	75
	5-day, 20°C BOD		2,100	81	2,100	77	3,400	88	3,100	76
	grease and oil		180	87	110	90	770	94	98	48
Phosphate, mg/ℓP							2.3	65	61	59
mg/ℓ N	ammonia N						55	75	111	77
	organic N						160	81	129	68
Solids	total, mg/ℓ	total					4,600	0	5,300	5
		volatile								
	suspended, mg/ℓ	total	1,880	84	1,760	89	2,000	85	2,700	86
		volatile								
	settleable, mℓ/ℓ									

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BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER

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Table 32. Wastewater Treatment Plant Results (Contined)

DATE		11-10-78		11-14-78		11-16-78		11-21-78	
		in	out	in	out	in	out	in	out
me/ℓ	pH3 alkalinity								
	pH7 acidity								
wastewater temperature, °F		98	96	99	88	100	91	96	89
mg/ℓ chloride									
µmhos/cm at 25°C									
pH at 25°C		6.7	3.8	6.9	3.8	7.3	3.8	6.7	3.8
pH after LS + H_2SO_4		2.7		2.8		2.8		2.65	
gal/hr		44,800		39,200		47,200		47,200	
mg/ℓ LS		0.0689		0.0625		0.0782		0.0767	
mg/ℓ COD in									
mg/ℓ	LS	393		372		345		356	
	H_2SO_4	1,157		1,296		984		922	
	$Ca(OH)_2$	516		356		415		517	
		in	%	in	%	in	%	in	%
mg/ℓ	COD	5,700	81	5,950	77	4,410	75	4,640	62
	5-day, 20°C BOD	3,400	80	3,400	77	2,900	77	3,800	87
	grease and oil	660	86	1,030	91	555	87	700	66
Phosphate, mg/ℓP		38	29	36	33	43		29	
mg/ℓ N	ammonia N	86	61	44	36	90	57	100	
	organic N	94	35	159	78	140	67	100	
Solids	total, mg/ℓ total	4,650		5,500	16	5,520	16	3,500	9
	total, mg/ℓ volatile								
	suspended, mg/ℓ total	2,500	79	2,490	88	1,320	80	2,050	71
	suspended, mg/ℓ volatile								
	settleable, mℓ/ℓ								

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BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER
EPA-287 (Cin.) (4-78)

Table 32. Wastewater Treatment Plant Results (Continued)

		DATE	11-28-78		11-29-78		11-30-78		12-5-78	
			in	out	in	out	in	out	in	out
me/ℓ	pH3 alkalinity									
	pH7 acidity									
wastewater temperature, °F			99	91	100	92	100	94	101	89
mg/ℓ chloride										
μmhos/cm at 25°C										
pH at 25°C			6.8	3.8	7.3	3.8	6.6	3.8	6.8	3.8
pH after LS +H_2SO_4			2.6		2.7		2.4		2.75	
gal/hr			44,400		42,400		41,600		40,000	
mg/ℓ LS / mg/ℓ COD in			0.0468		0.0283		0.0435		0.0751	
mg/ℓ	LS		265		297		302		410	
	H_2SO_4		916		838		1,020		1,078	
	$Ca(OH)_2$		285		337		345		331	
			in	%	in	%	in	%	in	%
mg/ℓ	COD		5,660	82	10,500	67	6,940	73	5,460	67
	5-day, 20°C BOD		2,900	82	2,900	74	3,200	61	2,450	63
	grease and oil		835	89	600	88	910	85	840	75
Phosphate, mg/ℓP			160	88	30	36	20	36	8.6	
mg/ℓ N	ammonia N		90	44	60	0	90	44	70	43
	organic N		140	93	40		190	58	240	63
Solids	total, mg/ℓ	total	6,510	21	5,540	17	4,730	1	5,300	6
		volatile								
	suspended, mg/ℓ	total	2,800	84	2,200	85	2,860	86	2,200	73
		volatile								
	settleable, mℓ/ℓ									

Table 32. Wastewater Treatment Plant Results (Continued)

		DATE	12-7-78		12-14-78		12-18-78		12-19-78	
			in	out	in	out	in	out	in	out
$\frac{me}{\ell}$	pH3 alkalirity									
	pH7 acidity									
wastewater temperature, °F			104	102	100	99	93	63	104	
mg/ℓ chloride			365	296	230	300	580	330	700	570
μmhos/cm at 25°C										
pH at 25°C			7.4	3.8	6.7	3.5	7.2	3.9	6.9	3.8
pH after LS +H_2SO_4			2.55		2.65		2.45		2.55	
gal/hr			40,000		44,400		37,600		44,000	
mg/ℓ LS			0.1870		0.1103		0.0727		0.1473	
mg/ℓ COD in										
mg/ℓ	LS		445		621		411		486	
	H_2SO_4		1,010		526		1,284		1,114	
	$Ca(OH)_2$		359		594		603		572	
			in	%	in	%	in	%	in	%
mg/ℓ	COD		2,380	78	5,630	57	5,650	73	3,300	77
	5-day, 20°C BOD		1,450	56	2,550	58	3,100	70	1,800	72
	grease and oil		148	69	390	62	1,200	53	960	33
Phosphate, mg/ℓP			3.2	28	4.2	76	1.9		0.4	
$\frac{mg}{\ell}$ N	ammonia N		190	74	60	0				
	organic N		130	69	220	64				
Solids	total, mg/ℓ	total	3,940		4,240		6,400	23	4,300	
		volatile								
	suspended, mg/ℓ	total	2,100	82	620		10,600	88	2,200	75
		volatile								
	settleable, mℓ/ℓ									

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Table 32. Wastewater Treatment Plant Results (Continued)

DATE			12-20-78		12-21-78		12-27-78		12-28-78	
			in	out	in	out	in	out	in	out
me/ℓ	pH3 alkalinity									
	pH7 acidity									
wastewater temperature, °F			98	95	97	91	102	92	101	101
mg/ℓ chloride			820	465	585	450	470	400	470	460
µmhos/cm at 25°C										
pH at 25°C			6.5	3.8	6.1	3.9	6.7	4.05	6.8	4.2
pH after LS +H_2SO_4			2.65		2.7		2.7		2.7	
gal/hr			43,200		45,600		47,400		50,000	
mg/ℓ LS / mg/ℓ COD in			0.1115		0.0737		0.062		0.122	
mg/ℓ	LS		348		381		341		366	
	H_2SO_4		980		1,074		940		988	
	$Ca(OH)_2$		558		587		513		574	
			in	%	in	%	in	%	in	%
mg/ℓ	COD		3,120	80	5,170	71	5,500	60	3,000	76
	5-day, 20°C BOD		2,000	80	3,600	73	3,000	54	2,200	73
	grease and oil		395	89	650	94	600	88	770	87
Phosphate, mg/ℓP			16		3.6		3.5		3.5	
mg/ℓ N	ammonia N									
	organic N									
Solids	total, mg/ℓ	total	6,950	26	6,360	15	4,200	12	4,200	0
		volatile								
	suspended, mg/ℓ	total	2,240	86	2,800	72	2,000	83	2,400	85
		volatile								
	settleable, mℓ/ℓ									

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BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS

PAGE NUMBER

Table 32. Wastewater Treatment Plant Results (Continued)

	DATE	1-4-79		1-5-79		1-9-79		1-10-79	
		in	out	in	out	in	out	in	out
$\frac{me}{\ell}$	pH3 alkalinity								
	pH7 acidity								
wastewater temperature, °F		97	90	98	92	96	85	99	90
mg/ℓ chloride		610	600	440	530	320	390	460	600
µmhos/cm at 25°C									
pH at 25°C		6.5	4	6.4	4.2	6.8	3.8	6.4	3.8
pH after LS +H_2SO_4		2.7		2.7		2.7		2.85	
gal/hr		40,272		42,000		41,200		39,200	
mg/ℓ LS		0.119		0.063		0.088		0.090	
mg/ℓ COD in									
mg/ℓ	LS	415		389		380		542	
	H_2SO_4	972		920		855		1,078	
	$Ca(OH)_2$	671		622		391		503	
		in	%	in	%	in	%	in	%
mg/ℓ	COD	3,500	66	6,200	60	4,300	40	6,000	63
	5-day, 20°C BOD	2,050	60	4,100	61	2,650	43	3,850	60
	grease and oil	270	88	46	41	44	45	740	81
Phosphate, mg/ℓP		0.15		0.2		0.49		0.34	
$\frac{mg}{\ell}$ N	ammonia N								
	organic N								
Solids	total, mg/ℓ total	3,300		5,200		5,000		5,300	9
	total, mg/ℓ volatile								
	suspended, mg/ℓ total	1,300	59	3,300	70	2,200	41	4,100	76
	suspended, mg/ℓ volatile								
	settleable, mℓ/ℓ								

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Table 32. Wastewater Treatment Plant Results (Continued)

			DATE 1-11-79		1-15-79		1-23-79 Tank II		1-24-79 Tank II	
			in	out	in	out	in	out	in	out
me/ℓ	pH3 alkalinity									
	pH7 acidity									
wastewater temperature, °F			97	92	90	78	96	96	95	91
mg/ℓ chloride			390	250	460	250				
µmhos/cm at 25°C										
pH at 25°C			6.7	3.8	6.8	3.8	6.8	3.8	6.8	3.8
pH after LS +H_2SO_4			2.65		2.55		2.7		2.5	
gal/hr			44,400		42,400		25,252		24,282	
mg/ℓ LS / mg/ℓ COD in			0.090		0.303		0.133		0.135	
mg/ℓ	LS		403		698		467		460	
	H_2SO_4		1,086		1,227		1,172		1,323	
	$Ca(OH)_2$		666		677		604		628	
			in	%	in	%	in	%	in	%
mg/ℓ	COD		4,500	53	2,300	48	3,500	40	3,400	12
	5-day, 20°C BOD		2,650	49	1,590	38	2,180	35	2,790	25
	grease and oil		470	62	370	24	390	56	1,300	96
Phosphate, mg/ℓP			0.53		0.68					
mg/ℓ N	ammonia N									
	organic N									
Solids	total, mg/ℓ	total	6,000	0	5,200					
		volatile								
	suspended, mg/ℓ	total	1,600	55	3,400	38	5,000	70	6,000	43
		volatile								
	settleable, mℓ/ℓ									

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BOTTOM OF IMAGE AREA OUTSIDE DIMENSION FOR TABLES AND ILLUSTRATIONS
PAGE NUMBER

Table 32. Wastewater Treatment Plant Results (Continued)

DATE			1-25-79 Tank II		2-5-79		2-6-79		2-8-79	
			in	out	in	out	in	out	in	out
me/ℓ	pH3 alkalinity									
	pH7 acidity									
wastewater temperature, °F			96	96	100	93	103	98	102	102
mg/ℓ chloride					310	380	460	380	360	380
µmhos/cm at 25°C					5,500	5,600	4,800	4,900	6,800	5,800
pH at 25°C			7.3	3.9	6.8	3.7	7.1	3.8	6.0	3.7
pH after LS $+H_2SO_4$			2.6		2.46		2.35		2.03	
gal/hr			24,756		46,000		42,800		49,600	
mg/ℓ LS / mg/ℓ COD in			0.081		0		0.0662		0.0388	
mg/ℓ	LS		357		0		450		345	
	H_2SO_4		1,151		1,083		1,016		1,538	
	$Ca(OH)_2$		541		1,250		1,276		1,841	
			in	%	in	%	in	%	in	%
mg/ℓ	COD		4,400	66	6,200	65	6,800	80	8,900	75
	5-day, 20°C BOD		3,100	73	3,600	64	4,200	81	5,200	75
	grease and oil		400	90	1,200	8	630	91	1,000	90
Phosphate, mg/ℓP					1.2		4.8		18	
mg/ℓ N	ammonia N								100	59
	organic N								160	76
Solids	total, mg/ℓ	total			5,100	0	4,200		6,600	14
		volatile			1,900	53	890	73	3,100	76
	suspended, mg/ℓ	total	1,400	89	4,000	25	2,600	89	4,300	77
		volatile			1,300	32	2,300	90	2,500	74
	settleable, mℓ/ℓ									

Table 32. Wastewater Treatment Plant Results (Continued)

DATE			2-9-79		2-12-79		2-13-79		2-14-79	
			in	out	in	out	in	out	in	out
$\frac{me}{\ell}$	pH3 alkalinity									
	pH7 acidity									
wastewater temperature, °F			97	100	99	88	100	95	97	97
mg/ℓ chloride			400	370			500	530		
μmhos/cm at 25°C			4,860	4,970			4,750	5,020		
pH at 25°C			7.06	3.9	7.3	4.1	6.8	3.9	7.2	4.2
pH after LS +H_2SO_4			1.9		2.15		2.45		2.5	
gal/hr			48,200		43,500		42,400		50,400	
$\frac{\text{mg/}\ell\text{ LS}}{\text{mg/}\ell\text{ COD in}}$			0.0151		0.0462		0.0594		0.0517	
mg/ℓ	LS		281		291		395		310	
	H_2SO_4		1,406		1,216		1,071		1,029	
	$Ca(OH)_2$		834		919		490		806	
			in	%	in	%	in	%	in	%
mg/ℓ	COD		18,600	87	6,300	81	6,650	86	6,000	72
	5-day, 20°C BOD		12,000	88	3,880	80	3,900	84	3,400	74
	grease and oil		1,240	98	1,400	89	915	94	680	95
Phosphate, mg/ℓP			2.9							
$\frac{mg}{\ell}$ N	ammonia N		100	61			72	44		
	organic N		180	100			190	82		
Solids	total, mg/ℓ	total	6,100	13			5,690	22		
		volatile					1,890	98		
	suspended, mg/ℓ	total	3,540	88	4,700	81	2,540	94	3,900	84
		volatile	3,460	88			2,320	94		
	settleable, mℓ/ℓ									

Table 32. Wastewater Treatment Plant Results (Continued)

		DATE	2-15-79		2-16-79		2-19-79		2-20-79	
			in	out	in	out	in	out	in	out
$\frac{me}{\ell}$	pH3 alkalinity									
	pH7 acidity									
wastewater temperature, °F			100	99	102	99	96	94	98	97
mg/ℓ chloride			410	410					430	430
μmhos/cm at 25°C			4,750	4,800					4,500	3,700
pH at 25°C			6.9	3.9	7.5	3.9	7.1	3.9	7	3.9
pH after LS +H_2SO_4			2.4		2.5		2.45		2.6	
gal/hr			46,000		48,400		47,600		49,000	
$\frac{mg/\ell\ LS}{mg/\ell\ COD\ in}$			0.0691		0.0653		0.0418		0.0545	
mg/ℓ	LS		304		294		314		300	
	H_2SO_4		1,026		1,090		1,020		1,092	
	$Ca(OH)_2$		560		515		629		145	
			in	%	in	%	in	%	in	%
mg/ℓ	COD		4,400	78	4,500	85	7,520	86	5,500	85
	5-day, 20°C BOD		2,400	75	2,850	87	4,200	83	3,000	84
	grease and oil		280	93	6		995	95	775	93
Phosphate, mg/ℓP									2	40
$\frac{mg}{\ell}$ N	ammonia N		178						102	45
	organic N		72						168	80
Solids	total, mg/ℓ	total	3,780						6,000	25
		volatile	590	56					4,100	85
	suspended, mg/ℓ	total	2,240	91	5,000	85	3,760	95	6,000	96
		volatile	1,600	89					5,800	96
	settleable, mℓ/ℓ									

Table 32. Wastewater Treatment Plant Results (Continued)

	DATE	2-21-79		2-22-79					
		in	out	in	out	in	out	in	out
me/ℓ	pH3 alkalinity								
me/ℓ	pH7 acidity								
wastewater temperature, °F		99	99	99	112				
mg/ℓ chloride									
µmhos/cm at 25°C									
pH at 25°C		7.3	4.2	7.2	4.2				
pH after LS +H_2SO_4		2.6		2.45					
gal/hr		49,600		48,800					
mg/ℓ LS		0.0653		0.0672					
mg/ℓ COD in									
mg/ℓ	LS	320		321					
mg/ℓ	H_2SO_4	1,114		1,105					
mg/ℓ	$Ca(OH)_2$	343		364					
		in	%	in	%	in	%	in	%
mg/ℓ	COD	4,900	81	4,780	76				
mg/ℓ	5-day, 20°C BOD	3,000	80	2,800	75				
mg/ℓ	grease and oil	510	93	1,180	93				
Phosphate, mg/ℓP									
mg/ℓ N	ammonia N								
mg/ℓ N	organic N								
Solids	total, mg/ℓ total								
Solids	total, mg/ℓ volatile								
Solids	suspended, mg/ℓ total	2,200	84	3,350	89				
Solids	suspended, mg/ℓ volatile								
Solids	settleable, mℓ/ℓ								

Table 32. Wastewater Treatment Plant Results (Continued		DATE	Mean Values		Standard Deviations (SD)		$\frac{SD}{Mean}$			
			in	out	in	out	in	out	in	out
$\frac{me}{\ell}$	pH3 alkalinity		19.4	9.3	2.4	1.9	0.12	0.21		
	pH7 acidity		-7.3	2.3	1.5	6.3	-0.20	2.7		
wastewater temperature, °F			101	97	5	8	0.054	0.083		
mg/ℓ chloride			523	439	183	111	0.35	0.21		
μmhos/cm at 25°C			4,687	5,073	701	475	0.15	0.094		
pH at 25°C			6.97	3.83	0.34	0.30	0.048	0.079		
pH after LS + H_2SO_4			2.56		0.25		0.097			
gal/hr (Both Tanks)			44,152		3,696		0.0837			
$\frac{mg/\ell \text{ LS}}{mg/\ell \text{ COD in}}$			0.0977		0.0448		0.459		Calculated Average Effluent Concentration, mg/1	
mg/ℓ	LS		388		101		0.26			
	H_2SO_4		1,106		175		0.16			
	$Ca(OH)_2$		560		249		0.44			
			in	%	in	%	in	%		
mg/ℓ	COD		4,607	71	2,191	13	0.48	0.19	1,336	
	5-day, 20°C BOD		2,945	71	1,350	13	0.46	0.19	854	
	grease and oil		570	82	331	20	0.58	0.24	103	
Phosphate, mg/ℓP			17	49	32	21	1.86	0.44	9	
$\frac{mg}{\ell}$ N	ammonia N		82	41	40	23	0.48	0.56	48	
	organic N		128	63	62	25	0.48	0.41	47	
Solids	total, mg/ℓ	total	5,335	12	909	9	0.17	0.73	4,695	
		volatile	2,335	63	811	13	0.35	0.21	864	
	suspended, mg/ℓ	total	2,462	78	1,471	17	0.60	0.22	542	
		volatile	1,695	83	1,316	16	0.78	0.19	288	
	settleable, mℓ/ℓ		8	82	8	16	0.98	0.20	1	

While the ratio

$$\frac{\text{mg/l Calcium Lignosulfonate}}{\text{mg/l COD in influent}} = R$$

varied considerably, there appeared to be no significant difference in % COD removal for values of R between 0.05 and 0.13 when $2.45 \leq pH \leq 2.85$. Consequently, there appears to be no reason for the dosage of Calcium Lignosulfonate in mg/l to exceed 5% of the influent COD concentration in mg/l. For an average COD of 4,607 mg/l, this means the Calcium Lignosulfonate dose could have averaged 230 mg/l with the same % COD removal that was obtained with an average Calcium Lignosulfonate dose of 388 mg/l. In other words it appears that the cost of Calcium Lignosulfonate could be reduced to about 60% of what was actually expended during the course of the project. Calcium Lignosulfonate also exerts a COD, and adding more than the stoichiometric quantity required adds to the effluent COD.

As expected, the % removal of BOD and COD was the same. In fact the identical values for the standard deviation and coefficient of variation of % removal as well as the almost identical values for the coefficient of variation of the COD and BOD concentrations strongly indicate that for this type of wastewater, COD and BOD are different ways of measuring the same thing. The 5-day, 20°C BOD is, on the average, 64% of the COD.

The ratio SD/mean for the influent ammonia and organic nitrogen concentrations was the same. The total nitrogen (ammonia+organic nitrogen) concentration averaged 210 mg/l with a standard deviation of 74 mg/l giving a SD/mean ratio of 0.35 which indicates that the total influent nitrogen concentration was less variable. The average % removal of total nitrogen was 58% with a standard deviation of 21% giving a SD/mean ratio of 0.36 which indicates that the % removal of total nitrogen was also less variable.

In the right hand column on the last page of Table 32 are the calculated average effluent concentrations (calculated from the average values given for influent concentration and % removal).

Table 33 shows the influent and effluent solids concentrations, % removal, and change in solids concentration. The % removal of volatile suspended solids (83%) is quite close to that observed for settleable solids (82%). The total change in solids concentration is relatively small (-12%) because of the 1,920 mg/l of suspended solids removed is largely offset by the 1,280 mg/l gain in dissolved solids. The gain in dissolved solids appears to be largely due to the chemicals added (2,054 mg/l of calcium lignosulfonate, sulfuric acid, and calcium hydroxide). The well water that supplies this plant contains the following ions:

	mg/l	me/l
Calcium	320	+ 16.0
Magnesium	59	+ 4.9
Sodium	720	+ 31.3
Bicarbonate	380	- 6.2
Chloride	130	- 3.7
Sulfate	2,000	- 41.6
Total of above ions	3,609	+ 0.7

Clearly there are few uses that this water would be fit for even before its use by this plant.

On February 15, 1979, 2 coliform analyses were made on the plant effluent with the following results (pH=3.9) :

Total coliform colonies per 100 ml	5,600
Fecal coliforms per 100 ml	6,600

TABLE 33. INFLUENT AND EFFLUENT SOLIDS CONCENTRATIONS AND % REMOVAL

	Influent solids concentration, mg/l		
	Inorganic	Volatile	Total
Suspended	767	1,695	2,462
Dissolved	2,233	640	2,873
Total	3,000	2,335	5,335
	Effluent solids concentration, mg/l		
Suspended	254	288	542
Dissolved	3,577	576	4,153
Total	3,831	864	4,695
	% Removal		
Suspended	67	83	78
Dissolved	--	10	--
Total	--	63	12
	Change in solids concentration, mg/l		
Suspended	- 513	- 1,407	- 1,920
Dissolved	+ 1,344	- 64	+ 1,280
Total	+ 831	- 1,471	- 640

WASTEWATER DISCHARGED TO THE SEWAGE TREATMENT PLANT

The first 31 days listed in Table 34 differ from the last 10 days in that, in the latter case, reclaimed water from the Alwatech wastewater treatment plant was used for the rendering condensers and cattle pen clean-up. This appears to have reduced the total hydraulic load on the sewage treatment plant as well as the grease and oil load and concentration going

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TABLE 34. - ANALYSES OF WATER DISCHARGED TO THE SEWAGE TREATMENT PLANT

Date (1)	Gallons Per Head (2)	pH at 25°C (3)	COD, mg/l (4)	5-Day 20°C BOD, mg/l (5)	Grease and Oil, mg/l (6)	Total Suspended Solids, mg/l (7)
10-2-78	301	7.7	1,203	720	53	560
10-3-78	311	6.8	1,600	950	597	720
10-4-78	315	6.8	1,540	1,100	93	600
10-5-78	293	6.9	1,590	1,100	89	570
10-6-78	315		2,227	1,100	85	460
10-10-78	234		1,980	1,460	78	990
11-6-78	385	7.3	925	580	110	340
11-8-78	384	7.4	1,350	850	84	560
11-14-78	525		1,190	700	86	330
11-16-78	402		1,140	710	76	300
11-21-78		7.0	1,170	530	81	978
11-28-78	398		1,180	680	115	440
11-29-78	425	7.9	1,630	740	390	890
11-30-78	364	6.6	2,010	1,290	180	820
12-5-78	441	6.8	1,410	967	1,730	360
12-7-78	402		790	700	45	20
12-14-78	347	6.7	2,360	1,067	200	880
12-18-78	405	6.6	1,220	720	36	940
12-19-78	439	6.8	800	530	20	600
12-20-78	397	6.8	810	500	66	470
12-21-78	391	7.2	1,340	960	61	800
12-27-78	390	7.1	1,300	780	50	270
12-28-78	410	7.5	740	560	90	500
1-4-79	378	6.8	1,200	850	470	460
1-5-79	397	6,8	2,200	1,480	15	2,200

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PAGE NUMBER
EPA-287 (Cin.) (4-76)

TABLE 34.- ANALYSES OF WATER DISCHARGED TO THE SEWAGE TREATMENT PLANT (CONTINUED)

Date (1)	Gallons Per Head (2)	pH at 25° (3)	COD, mg/l (4)	5-Day 20°C BOD, mg/l (5)	Grease and Oil, mg/l (6)	Total Suspended Solids, mg / l (7)
1-9-79	310	6.8	2,000	1,280	13	1,800
1-10-79	311	6.8	2,400	1,600	120	1,000
1-11-79	345	6.9	2,700	1,600	180	1,000
1-15-79	386	6.9	1,600	1,280	130	1,500
1-24-79	251	6.9	3,400	2,550	300	1,800
1-25-79	262		1,200	690	48	280
Mean	364	7.0	1,555	988	184	756
SD	64	0.3	621	435	317	497
SD/Mean	0.17	0.049	0.40	0.44	1.73	0.66
1-23-79	180	7.0	1,900	1,510	150	1,000
2-5-79	308		2,100	1,400	100	3,200
2-6-79	312		1,800	1,000	110	780
2-9-79	345		4,600	2,600	66	520
2-14-79	331		2,500	1,350	39	1,400
2-15-79	320		1,100	680	42	290
2-19-79	382		960	1,100	36	100
2-20-79	371		950	540	40	760
2-21-79	380		980	680	34	200
2-22-79	362		1,140	760	76	475
Mean	329	7.0	1,803	1,162	69	873
SD	59		1,128	608	39	907
SD/Mean	0.18		0.63	0.52	0.57	1.04

to the sewage treatment plant. The pH was 7 in both cases. There was no consistent relationship between unit water use (gallons per head of cattle killed) and unit COD discharged (lb COD per head of cattle killed). Pounds of COD per head of cattle killed is obtained by dividing the product of columns 2 and 4 in Table 34 by 120,000. For the first 31 days, 4.58 lb COD was discharged per head with a standard deviation of 1.50 lb COD/head giving an SD/mean ratio of 0.33. For the last 10 days, 4.85 lb COD was dicharged per head with a standard deviation of 3.24 lb COD/head giving an SD/mean ratio of 1.5. Consequently, there appeared to be no significant difference although unit water consumption was reduced by 35 gallons per head.

The water discharged to the sewage treatment plant is a mixture of 3 components: (1) cattle pen wash water, (2) wastewater from the rendering condensers, and (3) Alwatech effluent. Table 35 contains the concentrations and total contributions from these 3 components (concentrations and contributions from the cattle pens were calculated from the other observed values). Table 36 contains the concentrations and contributions from these 3 components in the absence of any wastewater treatment. Comparison of Tables 35 and 36 show that the Alwatech wastewater treatment plant was treating the wastewater that contributes 89% of the BOD, 82% of the grease and oil, and 86% of the suspended solids. Consequently, this treatment of 80% of the wastewater volume reduced the total concentrations and contributions discharged to the sewage treatment plant by 63% for BOD, 67% for grease and oil, and 67% for suspended solids.

TABLE 35. CONCENTRATIONS AND CONTRIBUTIONS TO THE WASTEWATER DISCHARGED TO THE SEWAGE TREATMENT PLANT

Contributing Wastewater Stream	Gallons per head	5-day, 20°C, BOD mg/l	Grease and Oil, mg/l	Total Suspended Solids, mg/l
Alwatech Plant Effluent	276	854	103	542
Rendering Condensers	53	422	112	375
Cattle Pens	14	5,772	2,053	6,417
Total with Alwatech treatment	343	988	184	756
		5-day, 20°C, BOD, lb/head	Grease and Oil, lb/head	Total Suspended Solids, lb/head
Alwatech Plant Effluent	276	1.96	0.24	1.25
Rendering Condensers	53	0.19	0.05	0.17
Cattle Pens	14	0.67	0.24	0.75
Total with Alwatech Treatment	343	2.82	0.53	2.17

TABLE 36. CONCENTRATIONS AND CONTRIBUTIONS TO THE WASTEWATER DISCHARGED TO THE SEWAGE TREATMENT PLANT IN THE ABSENCE OF WASTEWATER TREATMENT.

Contributing Wastewater Stream	Gallons per head	5-day, 20°C, BOD, mg/l	Grease and Oil, mg/l	Total Suspended Solids, mg/l
Alwatech Plant Influent	276	2,945	570	2,462
Rendering Condensers	53	422	112	375
Cattle Pens	14	5,772	2,053	6,417
Total with No Treatment	343	2,671	560	2,301
		5-day, 20°C, BOD, lb/head	Grease and Oil, lb/head	Total Suspended Solids, lb/head
Alwatech Plant Influent	276	6.77	1.31	5.66
Rendering Condensers	53	0.19	0.05	0.17
Cattle Pens	14	0.67	0.24	0.75
Total with No Treatment	343	7.63	1.60	6.58

BOTTOM SLUDGE PRODUCTION

Table 37 shows that about 28% of the total wet sludge volume produced is bottom sludge from the air flotation tanks.

SLUDGE COMPOSITION

Table 38 contains 87 sludge analyses. The following abbreviations are used to indicate the status of the sludge:

W = Wet sludge before neutralization with $Ca(OH)_2$

N = Neutralized sludge after neutralization with $Ca(OH)_2$

C = Centrifuged sludge

D = Dried sludge

Fixed solids is equivalent to inorganic solids. All % values of fixed solids, grease and oil, and protein are % of dry solids.

The pH of the wet (W) sludge averaged 5.3 while the pH of the neutralized (N) sludge averaged 7.6. It will be noticed that this latter pH value of 7.6 differs considerably from the average value listed for column 9 of Table 29 (pH=9.1). The difference is due to the fact that the pH value of 9.1 corresponds with the pH obtained

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TABLE 37. BOTTOM SLUDGE PRODUCTION

Week				Gallons of Bottom Sludge			% of Total
Month (1)	Days (2)	Year (3)	Days (4)	Tank I (5)	Tank II (6)	Total (7)	Sludge Produced (8)
September	18-22	78	5	10,120			
October	2-7	78	6		15,640		
October	23-28	78	6	14,034	13,984	28,018	32.5
November	20-25	78	6	8,096	8,832	16,928	26.5
November December	27-30 1-2	78	6	9,752	9,752	19,504	27.3
December	4-8	78	5	8,305	8,305	16,610	26.6
December	11-15	78	5	6,072	6,072	12,144	22.4
December	18-22	78	5	9,368	9,370	18,738	29.3
December	26-29	78	4	6,072	6,072	12,144	25.1
January	2-6	79	5	6,888	6,888	13,776	27.5
January	8-12	79	5	8,698	8,348	17,046	37.2
January	15-19	79	5				23.7
January	22-26	79	5				31.7
January February	29-31 1-2	79	5	8,119	9,150	17,269	20.8
Totals			52	85,404	86,773	172,177	
Average Per Day (Mean)						3,311	27.6
Standard Deviation (SD)							4.6
SD/Mean							0.17

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PAGE NUMBER
EPA-287 (Cin.)
(6-78)

TABLE 38. SLUDGE COMPOSITION

Date			pH at 25°C		% solids			NH_3 - N, mg/1				% fixed solids			% grease and oil			% protein			
Mo.	day	yr.	W	N	W	C	D	W	N	C	D	W	C	D	W	C	D	W	N	C	D
7	5	78					92										11				32
7	6	78				43	95									39	9			14	
7	6	78				42	94									34	12			14	29
7	7	78					95										9				32
7	8	78					94										12				37
7	10	78					93										9				31
7	11	78				39	94									14	9				
7	11	78				42	94									20	10			24	34
7	12	78					90										8				30
7	13	78				39	94									10	14				
7	13	78				39										9				30	
7	14	78					93										10				31
7	18	78					83										14				40
7	18	78					93										12				37
7	20	78					94										15				38

all % figures are % of dry solids.

TABLE 38. SLUDGE COMPOSITION (CONTINUED)

Date			pH at 25°C		% solids			NH_3 - N, mg/1				% fixed solids			% grease and oil			% protein			
Mo.	day	yr.	W	N	W	C	D	W	N	C	D	W	C	D	W	C	D	W	N	C	D
7	20	78					93										14				39
7	21	78					92										7				25
7	24	78					93										9				24
7	25	78					93										8				34
7	26	78					86										7				34
7	28	78					90										8				37
7	29	78					72										11				26
7	31	78					89										11				27
8	1	78					89										10				32
8	2	78					82										12				40
8	3	78					82										10				44
8	5	78					86										10				34
8	7	78					84										10				31
8	8	78					88										11				32
8	10	78					87										10				35

all % figures are % of dry solids.

TABLE 38. SLUDGE COMPOSITION (CONTINUED)

Date			pH at 25°C		% solids			NH$_3$ - N, mg/l				% fixed solids			% grease and oil			% protein			
Mo.	day	yr.	W	N	W	C	D	W	N	C	D	W	C	D	W	C	D	W	N	C	D
8	10	78					93										12				35
8	11	78					90										11				37
8	12	78					82										8				34
8	14	78					85										13				40
8	15	78					87										11				40
8	16	78					85										12				41
8	16	78	6.2	10.8	8	42	83					29	31	28	28	12	12				
8	17	78					84										13				46
8	21	78					93										9				33
8	22	78			8	42	88					22	29	33							
8	24	78	5.9	9.1	9	42	78					22	27	28							
9	13	78	5.0	10.5	6	44	82					27	27	29							
9	15	78	5.1	9.4	7	43						25	23								
9	19	78	5.5	9.4	7	45						25	28		26	15					
9	21	78			10	41	86					20	23	26							

all % figures are % of dry solids.

TABLE 38. SLUDGE COMPOSITION (CONTINUED)

Date			pH at 25°C		% solids			NH_3 - N, mg/l				% fixed solids			% grease and oil			% protein			
Mo.	day	yr.	W	N	W	C	D	W	N	C	D	W	C	D	W	C	D	W	N	C	D
9	26	78	5.2	9.3	7	41	88					27	21	25	32	20	10				
10	2	78	5.4	9.5	6	42	87	80	19,200	1,200	24,000	28	24	24	32	11	10	29	2	47	50
10	4	78			8	43	83					26	26	24	28	10	14				
10	6	78			10	44						18	21		30	15					
10	10	78	5.0	6.2	7	42	90	200	600	800	550	22	29	28	42	11	11	7	6	9	49
11	6	78	6.0	6	8	50	92	130	720	23					37	15	12	36	28	29	34
11	8	78	5.1	5.3	8	47	81	310	370	440	400				24	20	16	37	37	45	46
11	14	78	5.1	5.5	10	39	81								34	15	14	33	30	39	50
11	16	78	5.2	10.2	9	36		500	300	300					26	13		33	33	37	
11	21	78	4.6	6.2	11	43		260	1,200	1,200					41	32		41	26	42	
11	28	78	5.2	6.7	7	44	88	160	190	2,900	340				24	21	18	40	41	4	6
11	29	78	5.3	7.0	8	44	89	240	460	340	300				35	16	16	13	41	7	42
11	30	78	5.8	6.4	9	47	89	550	800	270	500				25	16	14	38	38	41	45
12	5	78	5.3	11.5	16	40	87	300	200	200	2,900				19	9	10	21	21	34	32
12	7	78	5.1	6.4	17	39	83	200	1,000	4,400					26	10	11	21	20	46	47

all % figures are % of dry solids.

TABLE 38. SLUDGE COMPOSITION (CONTINUED)

Date			pH at 25°C		% solids			NH_3 - N, mg/1				% fixed solids			% grease and oil			% protein			
Mo.	day	yr.	W	N	W	C	D	W	N	C	D	W	C	D	W	C	D	W	N	C	D
12	14	78	5.3	7	11	51	86	300	1,200	300					34	16	5	32	31	26	42
12	18	78	5.7	7	9	47	95	540	400	270	2,000				23	12	11	31	30	27	25
12	19	78	5.5	6.5	10	43	91	730	350	2,200	300				27	16	12	38	31	36	33
12	20	78	5.1	6.3	16	42	84	180	800	450	540				45	12	10	29	22	43	41
12	21	78	5.4	6.5	11	40		290	630	230					31	10		31	31	33	
12	27	78	5.3	10.0	8	39	85	580	300	600	71				30	16	16	37	34	41	40
12	28	78	5.5	6.6	7		91	78	150		69				27		14	45	45		38
1	4	79	5.6	6.3	8	38	85	46	56	53					23	14	9	38	31	38	43
1	5	79	4.9	6.8	9	42	85	16	32	69					34	9	8	34	38	42	45
1	9	79	5.2	6.0	9	41	79	57	50	1,000	1,200				24	10	13	37	37	43	44
1	10	79	5.4	7.0	8	38	86	43	41	53	1,050				30	13	12	40		43	43
1	11	79	5.5	6.4	8	42	81	18	53	70	1,800				28	41	10	38	18	27	70
1	15	79	5.1	8.7	8	47	90	1,100	1,000	1,200					17	9	6	45	37	35	34
2	5	79	4.9	12.1	7	39	85	6.3	12	130					58	15	8	14	22	25	34
2	6	79	5.4	5.7	8	56	90	26	36	47					33	9	9	35	33	44	54

all % figures are % of dry solids.

TABLE 38. SLUDGE COMPOSITION (CONTINUED)

Date			pH at 25°C		% solids			NH_3 - N, mg/1				% fixed solids			% grease and oil			% protein			
Mo.	day	yr.	W	N	W	C	D	W	N	C	D	W	C	D	W	C	D	W	N	C	D
2	7	79	4.8	8.8	9	48	90	8.3	6.8	12					34	18	9	32	31	49	54
2	8	79			9	45	87								42	11	11	31	29	46	45
2	9	79	3.7	9.4	8	55	92	110	78	440					35	12	11	35	25	36	42
2	12	79	5.4	6	7	43	95					10	13		35	13	7	39	39	33	24
2	13	79	4.7	8.3	9	44	92					11	14		38	13	11	36	43	39	37
2	14	79	5.9	6	12	44	91					11	14		38	11	9	33		48	43
2	15	79	5.9		12	44	93						14		38	11	5	33		48	43
2	16	79	5.7	8.2	11	46	93					10	14		30	10	9	30	31	35	41
2	19	79		6	12	51	91								28	14	9	24	24	29	46
2	20	79	5.1	6.2	11	50	93	490		1,600		9	14		31	19	10	28		32	36
2	21	79	5.4	6.4	9	47	93	720		700					34	9	6	43		37	36
2	22	79	5.3		13	44	92	160		290					36	11		30		39	46
MEAN			5.3	7.6	9.3	44	88	272	1,108	726	2,401	20	22	27	32	15	11	32	30	34	38
SD			0.4	1.8	2.5	4	5	264	3,574	972	6,030	7	6	3	7	7	3	8	10	11	9
SD/MEAN			0.081	0.24	0.26	0.095	0.054	0.971	3.224	1.339	2.511	0.36	0.29	0.11	0.23	0.48	0.24	0.26	0.32	0.33	0.23

all % figures are % of dry solids.

immediately on completion of the addition and mixing of $Ca(OH)_2$, whereas the pH value of 7.6 is the equilibrium or ultimate pH value that the sludge has after sufficient time. In other words, the sludge pH drops by (9.1-7.6 =) 1.5 pH units after mixing is complete, hence the need to achieve a relatively high pH initially.

The 9% solids concentration of the wet sludge as increased to 44% by the centrifuge (C), and still further to 88% by drying (D). The ammonia nitrogen concentrations in the sludge at all stages (W,N,C, and D) were so extremely variable that it appears no useful generalizations can be made.

The average composition of the sludge at the various stages is as shown in Table 39.

TABLE 39. AVERAGE SLUDGE COMPOSITION

Components	Wet Sludge (W)	Centrifuged Sludge (C)	Dried Sludge (D)
% fixed solids	20	22	27
% grease and oil	32	15	11
% protein	32	34	38
% other	16	29	24
% Total	100	100	100

The results tabulated in Table 39 are shown graphically in Figure 11. While the % grease and oil declines with increasing % solids, both % fixed solids and % protein increase with increasing % solids.

DRIED SLUDGE PRODUCTION

For the period July 5, 1978, through February 23, 1979, 34 weeks of dried sludge production data were obtained. However, for various reasons, not all of the sludge produced was dried every week. Therefore, Table 40 contains only the data for those weeks where all the sludge produced was dried.

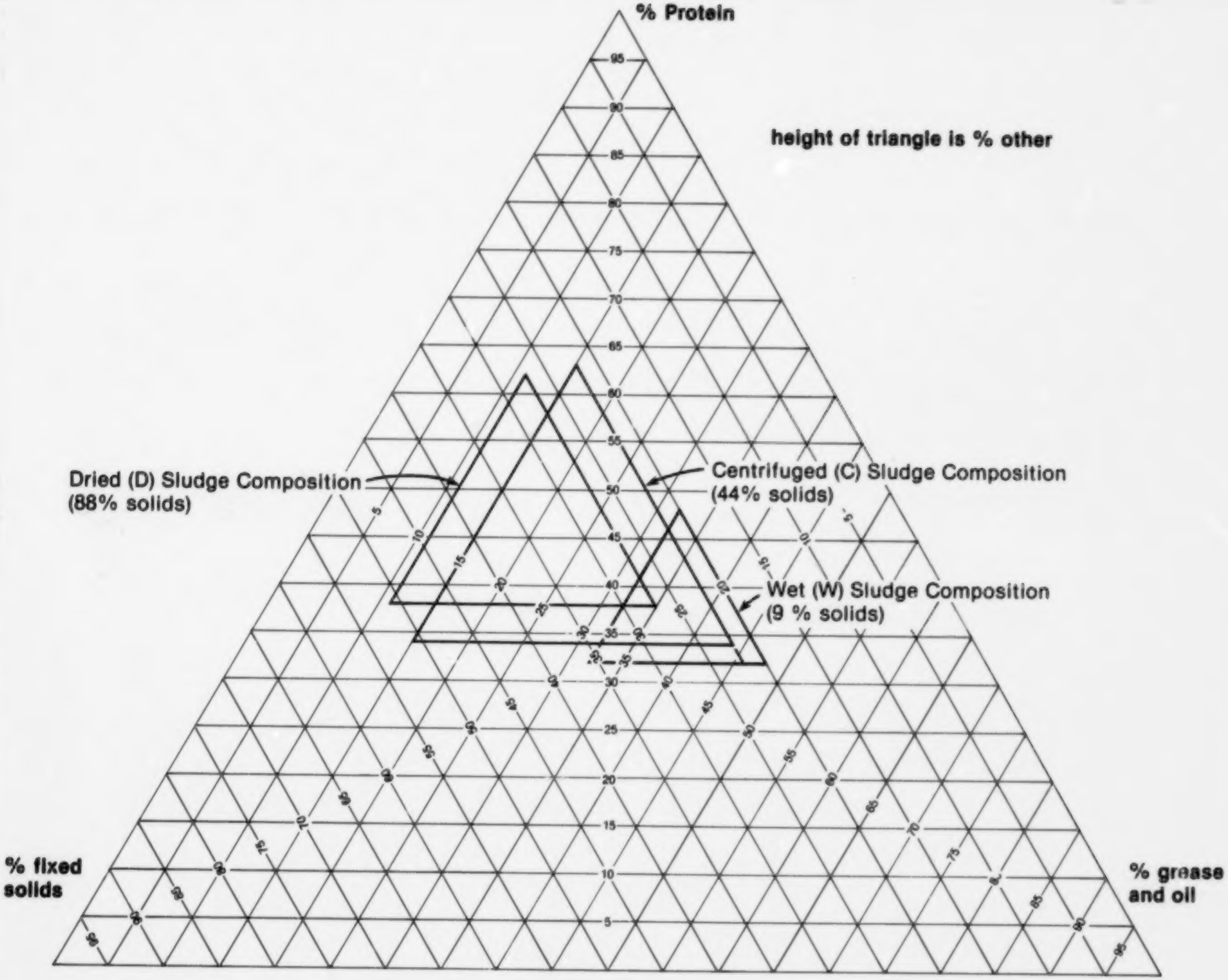

Figure 11.
Average Sludge Composition

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PAGE NUMBER

TABLE 40 DRIED SLUDGE PRODUCTION

Week	lb solids / 1,000 lb live
April 24-28, 1978	4.51
May 15-21, 1978	5.54
May 22-26, 1978	4.76
June 12-16, 1978	5.54
July 5-9, 1978	6.02
July 24-29, 1978	4.75
July 31-August 5, 1978	6.74
August 5-21, 1978	5.38
August 14-18, 1978	4.71
October 16-21, 1978	4.72
October 23-28, 1978	4.57
October 30-November 5, 1978	5.09
November 20-25, 1978	5.58
November 27-December 2, 1978	4.45
December 4-8, 1978	3.61
January 29-February 2, 1979	4.46
February 12-17, 1979	5.19
February 19-23, 1979	4.36
18 Week Average	5.00
Standard deviation (SD)	0.72
SD/mean	0.14

Apparently 0.5% of the incoming cattle weight winds up as dried sludge with relatively little variation from week to week.

DEVELOPMENTS DURING THIS PROJECT

It should be noted that some process development work was carried out during the course of this project. This sometimes shows up in the data as apparently erratic results. Also this is the reason that sometimes one or both flotation tanks were temporarily out of service for modifications.

Shortly after the plant was put in operation for the first time, it was observed that the separation of the precipitated solids in the flotation tank was not satisfactory. It is believed that this happened because:

(1) The original design of the flotation tank internal equipment was inappropriate for the relatively high (compared to European slaughterhouses) wastewater temperatures experienced (roughly 100°F), and

(2) Biological activity in the clarifier/balancing tank upstream from the Alwatech plant was encouraged by wastewater temperatures near the mesophilic optimum.
Wastewater temperatures of European slaughterhouses seldom exceed 70°F.

Alwatech reports that the development work carried out on the flotation tanks used in this project has resulted in up to 60% increases in plant capacity in European installations.

From Table 25, it can be observed that the rendering condenser water was bypassed around the Alwatech plant beginning August 29, 1978. From Table 32, it can be calculated that the average wastewater temperature before August 29, 1978, was 108°F, and after this date it averaged 104°F (through October 18, 1978), but the difference could be at least in part due to weather differences between July and August, and September and October. Therefore, the effectiveness of by-passing the condenser wastewater in reducing the wastewater temperature appears to be small at most. The optimum temperature for the growth of mesophilic anaerobic microorganisms is about 100°F.

It is believed that biological activity in the clarifier/balancing tank may also influence the effectiveness of nitrogen removal from the wastewater and consequently the protein concentration in the recovered product. From equation 14 it is clear that temperature has a direct effect on organic nitrogen removal efficiency. From this equation it is clear that pH values of less than about 6, organic nitrogen removal efficiency increases with temperature, and the rate of this increase is greater the lower the pH used.

Using the data in Table 38, the average protein concentration in the dried sludge during this project was as shown in Table 41. From this table it appears that with the possible exception of July, 1978, the protein concentration in the dried sludge remained roughly constant.

TABLE 41. AVERAGE PROTEIN CONCENTRATION IN THE DRIED SLUDGE

Month	Year	Average Protein Concentration in the Dried Sludge, %
July	1978	32
August	1978	37
September	1978	--
October	1978	50
November	1978	37
December	1978	37
January	1979	47
February	1979	42

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SECTION 7

ANALYSIS OF OBSERVED DATA

ORGANIC NITROGEN REMOVAL EFFICIENCY

Equation 1 can be modified as follows:

$$F=0.54T+52\ pH-6.6\ (pH)^2-0.44\ xR-0.091T\ (pH)+0.12\ xR\ (pH)-60 \quad (10)$$

where

F= organic nitrogen removal efficiency, %
T= Temperature, °C
x= Conversion constant $=D/R$, mg/l
D= Dose, mg/l
$R= \frac{\text{mg/l LS}}{\text{mg/l COD in}}$.

From Table 32, the average values of the quantities in equation 10 for those days where values of F are available are: $F=62.7\%$, $T=36.9^\circ C$, $pH=2.49$, $(pH)^2=6.29$, $R=0.0842$, $T\ (pH)=91.5$, and $R\ (pH)=0.211$. Substituting these values into equation 10 gives $x= -2{,}051$. Using these results, equation 10 can be written:

$$F=39+289R \quad (11)$$

However, by deleting one point ($R=0.187$, $F=69\%$), a least squares analysis (correlation coefficient=-0.74) gives:

$$F=104-536R \quad (12)$$

Equation 12 indicates that the value of x should be 3,828 and that the constant -60 should be changed to 5. Therefore, equation 10 becomes:

$$F=0.54T+52\ pH-6.6\ (pH)^2-1{,}684R-0.091T\ (pH)+459R\ (pH)+5 \quad (13)$$

By deleting 2 more points ($R=0.1529, F=17\%$, and $R=0.0689$, $F=35\%$) and comparing the results calculated by equation 13 with the observed values of F, the observed values of F are on the average 1% greater than the values of F given by equation 13. Changing equation 13 accordingly, one obtains:

$$F=0.54T+52\ pH-6.6\ (pH)^2-1{,}684R-0.091T\ (pH)+459\ R\ (pH)+6 \quad (14)$$

Comparison of the results calculated by equation 14 with the observed data gave a correlation coefficient of 0.84. This comparison is plotted in Figure 12.

After deleting the following 5 observations,

Observed Organic Nitrogen Removal, %	% COD Removal
3	59
17	61
37	65
35	81
64	57

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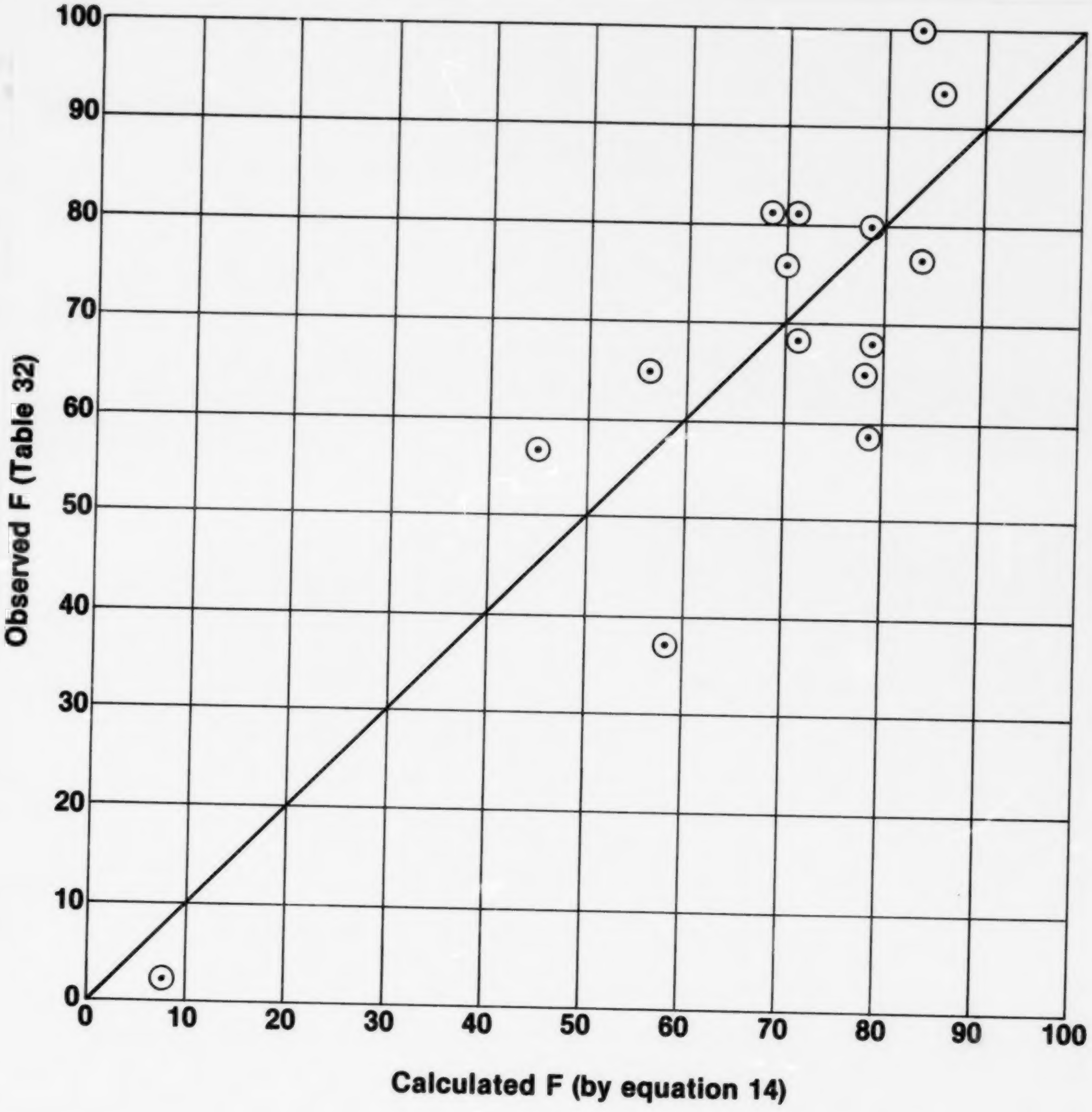

Figure 12.
Comparison of Calculated and Observed Organic Nitrogen Removal

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3/8"
PAGE NUMBER
EPA-287 (Cin.)
(4-76)

a least squares analyses of the remaining 13 pairs of observations gave the following relationship (correlation coefficient=0.82):

$$\% \text{ COD removal}=40+0.5F \tag{15}$$

CENTRIFUGE EFFICIENCY

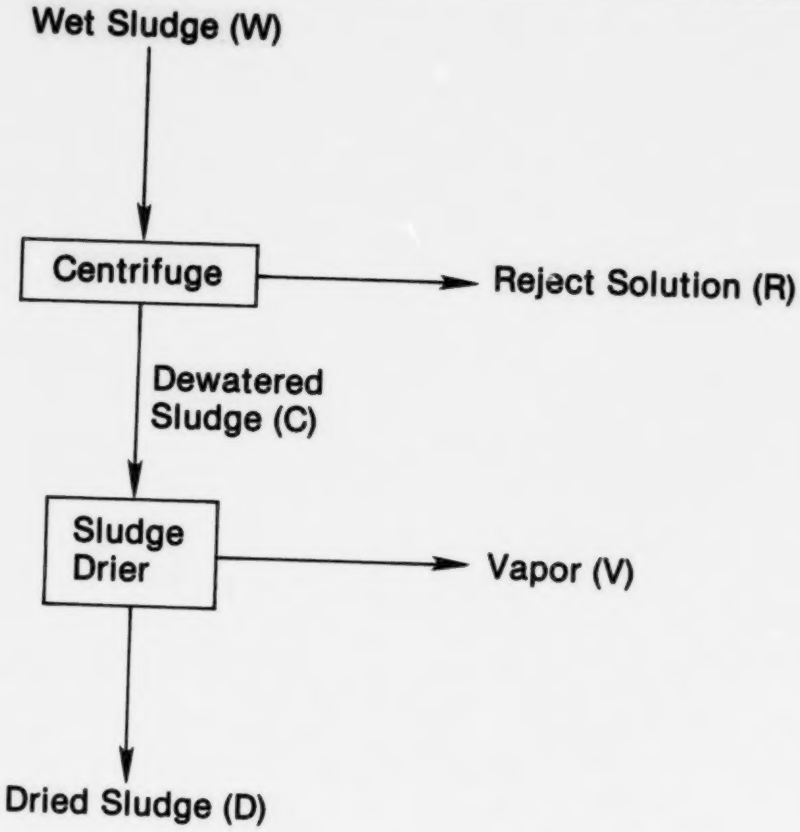
Figure 13 shows the material balance components of the sludge handling facilities. In order to quantitatively evaluate the performance of these facilities, 10 days of records were selected for detailed evaluation. These 10 days and their corresponding values from Table 38 are shown in Table 42. Observed quantities of wet, dewatered, and dried sludge are shown in Table 43. The quantities of solids are given in Table 44. These were calculated from the corresponding data in columns 4-6 of Table 42 and columns 2-4 of Table 43. Table 45 gives the quantities of protein, grease and oil in the wet, dewatered, and dried sludge. The quantities in Table 45 were calculated from the data in columns 7-12 of Table 42 and columns 2-4 of Table 44.

From Table 44 it is clear that only about 52% of the solids in the wet sludge winds up in the dewatered sludge, the remaining 48% of the solids is discharged in the reject solution. By contrast, over 96% of the solids in the dewatered sludge winds up in the dried sludge, so less than 4% of the solids are lost on drying.

From Table 45, it can be seen that about 66% of the protein in the wet sludge winds up in the dewatered sludge; the remaining 34% of the protein is discharged in the reject solution. However, all of the protein in the dewatered sludge winds up in the dried sludge, so none of the protein is lost on drying. Only 18% of the oil and grease in the wet sludge winds up in the dewatered sludge; the remaining 82% of the oil and grease is discharged in the reject solution. Also 76% of the oil and grease in the dewatered sludge winds up in the dried sludge, so 24% of the oil and grease is lost on drying.

Table 46 gives the averages of the various quantities depicted in Figure 13. The average values in columns 2-4 of Table 43, columns 2-4 of Table 44, columns 2-7 of Table 45 are shown in columns 1, 3, and 5 of Table 46 (Column 2=columnl minus column 3 and column 4=column 3 minus column 5). Also given in Table 46 are these same quantities per 100,000 pounds of wet sludge for ease of comparison. These latter values are represented in Figure 14.

If it is assumed that the purpose of the centrifuge is to put as much of the solids as possible into the dewatered sludge and as little water as possible into the dewatered sludge, then the centrifuge efficiencies are as calculated in Table 47. Assuming that the same criteria apply to the sludge drier, then these efficiencies are given in Table 48.


Wet Sludge (W)
Centrifuge
Reject Solution (R)
Dewatered Sludge (C)
Sludge Drier
Vapor (V)
Dried Sludge (D)

$$W = R + C$$
$$C = V + D$$
$$W = R + V + D$$

Figure 13.
Sludge Handling Products

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TABLE 42. SLUDGE COMPOSITION USED

Date			% solids			% grease and oil			% protein		
Mo.	day	yr.	W	C	D	W	C	D	W	C	D
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
2	9	79	7.5	55.3	91.7	35	12	11	35	36	42
2	8	79	9.1	45.2	86.5	42	11	11	31	46	45
2	7	79	9.0	47.9	89.7	34	18	9	32	49	54
2	6	79	8.2	55.5	89.9	33	9	9	35	44	54
2	5	79	6.9	39.4	85.0	58	15	8	14	25	34
1	15	79	7.6	47.0	89.5	17	9	6	45	35	34
1	11	79	7.9	42.3	80.8	28	41	10	38	27	70
1	10	79	7.7	38.0	85.7	30	13	12	40	43	43
1	9	79	8.7	40.6	79.3	24	10	13	37	43	44
1	5	79	9.4	42.3	84.8	34	9	8	34	42	45

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PAGE NUMBER
EPA-287 (Cin.) (9-78)

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TABLE 43. OBSERVED QUANTITIES OF WET, DEWATERED, AND DRIED SLUDGE

Date (1)	Weight of wet (W) sludge produced, pounds (2)	Weight of dewatered (C) sludge produced, pounds (3)	Weight of dried (D) sludge produced, pounds (4)
2-9-79	94,751	9,410	4,800
2-8-79	258,907	22,730	11,410
2-7-79	197,199	15,890	8,560
2-6-79	136,609	11,410	6,090
2-5-79	100,480	7,870	3,830
1-15-79	46,003	10,260	4,950
1-11-79	44,069	2,450	1,100
1-10-79	96,953	10,070	4,770
1-9-79	90,739	11,130	5,530
1-5-79	134,716	14,880	7,850
Average	120,043	11,610	5,889

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PAGE NUMBER
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(4-76)

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TABLE 44. SOLIDS PRODUCTION

Date (1)	Weight of solids in wet (W) sludge, pounds (2)	Weight of solids in dewatered (C) sludge, pounds (3)	Weight of solids in dried (D) sludge, pounds (4)
2-9-79	7,106	5,204	4,402
2-8-79	23,561	10,274	9,870
2-7-79	17,748	7,611	7,678
2-6-79	11,202	6,333	5,475
2-5-79	6,933	3,101	3,256
1-15-79	3,496	4,822	4,430
1-11-79	3,481	1,036	889
1-10-79	7,465	3,827	4,088
1-9-79	7,894	4,519	4,385
1-5-79	12,663	6,294	6,657
Average	10,155	5,302	5,113

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PAGE NUMBER
EPA-287 (Cin.)
(4-76)

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TABLE 45. PROTEIN, GREASE AND OIL IN SLUDGE

Date (1)	Weight of protein in wet (W) sludge, pounds (2)	Weight of protein in dewatered (C) sludge, pounds (3)	Weight of protein in dried (D) sludge, pounds (4)	Weight of oil and grease in wet (W) sludge, pounds (5)	Weight of oil and grease in dewatered (C) sludge, pounds (6)	Weight of oil and grease in dried (D) sludge pounds (7)
2-9-79	2,490	1,870	1,850	2,489	624	484
2-8-79	7,320	4,740	4,440	9,912	1,133	1,086
2-7-79	5,660	3,729	4,150	6,018	1,370	691
2-6-79	3,920	2,790	2,959	3,696	570	493
2-5-79	970	775	1,108	4,019	465	261
1-15-79	1,580	1,690	1,506	595	434	266
1-11-79	1,322	281	622	974	426	89
1-10-79	2,990	1,650	1,760	2,241	498	491
1-9-79	2,920	1,940	1,930	1,894	452	571
1-5-79	4,320	2,640	3,000	4,318	566	533
Average	3,349	2,211	2,333	3,616	654	497

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PAGE NUMBER
EPA-287 (Cin)
(4-76)

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TABLE 46. AVERAGE SLUDGE QUANTITIES

Component	Weight in wet (W) sludge, pounds (1)	Weight in reject (R) solution, pounds (2)	Weight in Dewatered (C) sludge, pounds (3)	Weight in vapor (V) from sludge drier, pounds (4)	Weight in Dried (D) sludge, pounds (5)
Protein	3,349	1,138	2,211	-122	2,333
Grease and oil	3,616	2,962	654	157	497
Other Solids	3,190	753	2,437	154	2,283
Water	109,888	103,580	6,308	5,532	776
Total	120,043	108,433	11,610	5,721	5,889
Total Solids	10,155	4,853	5,302	189	5,113
Per 100,000 pounds of wet sludge:					
Protein	2,791	948	1,843	-102	1,944
Grease and Oil	3,013	2,468	545	131	414
Other Solids	2,658	628	2,031	128	1,903
Water	91,573	86,317	5,257	4,610	647
Total	100,000	90,361	9,675	4,768	4,908
Total Solids	8,463	4,044	4,418	158	4,261

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PAGE NUMBER
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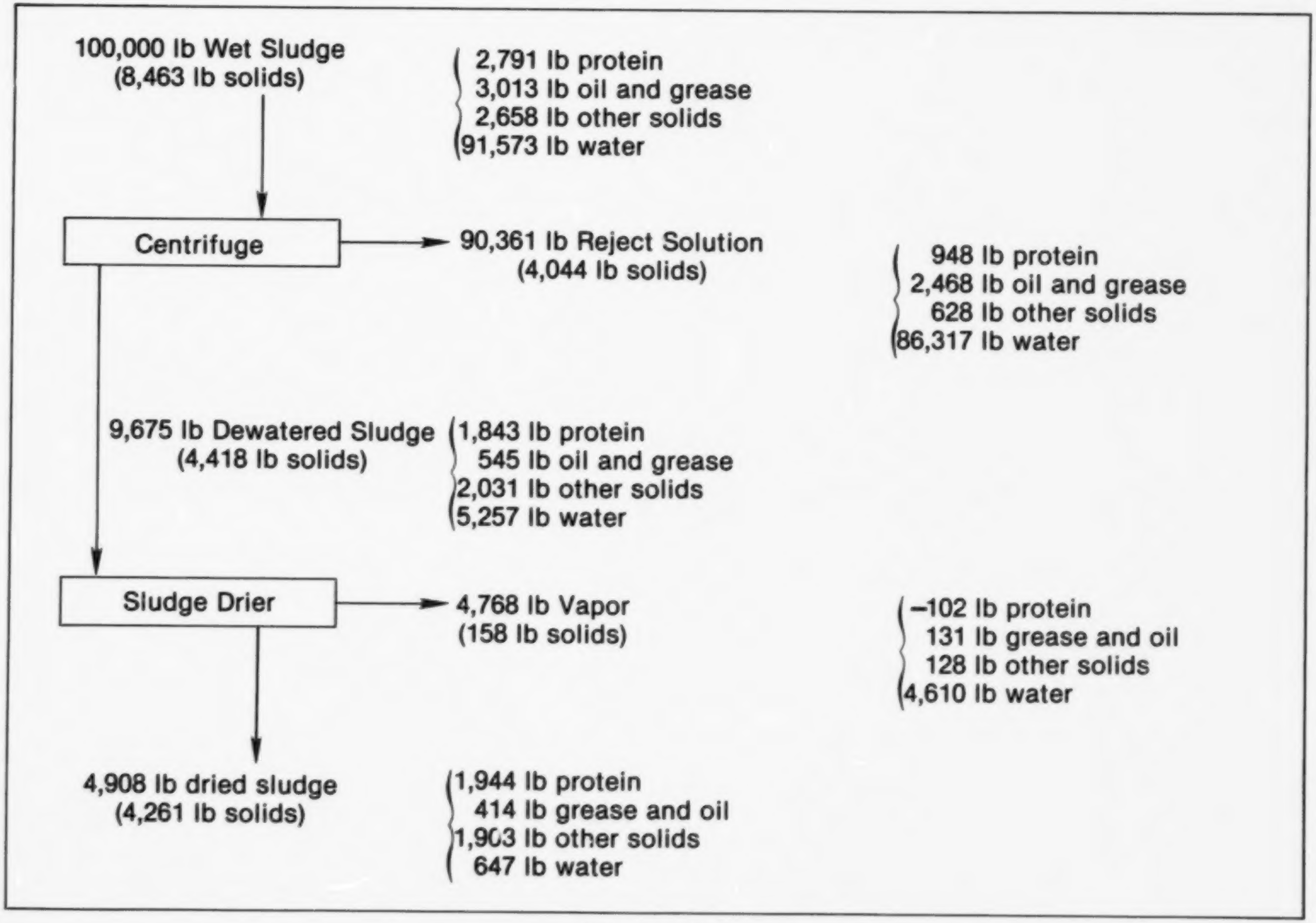
100,000 lb Wet Sludge
(8,463 lb solids)
2,791 lb protein
3,013 lb oil and grease
2,658 lb other solids
91,573 lb water
Centrifuge
90,361 lb Reject Solution
(4,044 lb solids)
948 lb protein
2,468 lb oil and grease
628 lb other solids
86,317 lb water
9,675 lb Dewatered Sludge
(4,418 lb solids)
1,843 lb protein
545 lb oil and grease
2,031 lb other solids
5,257 lb water
Sludge Drier
4,768 lb Vapor
(158 lb solids)
–102 lb protein
131 lb grease and oil
128 lb other solids
4,610 lb water
4,908 lb dried sludge
(4,261 lb solids)
1,944 lb protein
414 lb grease and oil
1,903 lb other solids
647 lb water

Figure 14.
Quantities per 100,000 pounds of Wet Sludge

TABLE 47. CENTRIFUGE EFFICIENCIES

	%
Water	94
Total Solids	52
Protein	66
Oil and Grease	21
Other Solids	76

TABLE 48. SLUDGE DRIER EFFICIENCIES

	%
Water	88
Total Solids	96
Protein	100
Oil and Grease	76
Other solids	94

From Figure 14 it is clear that the reject solution is about 4.5% solids, while the solids concentration in the vapor from the sludge drier is about 3.3%. The solids composition at the various stages can be calculated from the data in Table 46. This is represented graphically in Figure 15.

As Figure 15 clearly shows, the incoming wet sludge winds up in 3 places: (1) reject solution (R), (2) vapor (V) from the sludge drier, and (3) dried (D) sludge. Table 49 shows the ultimate fate of the incoming wet sludge.

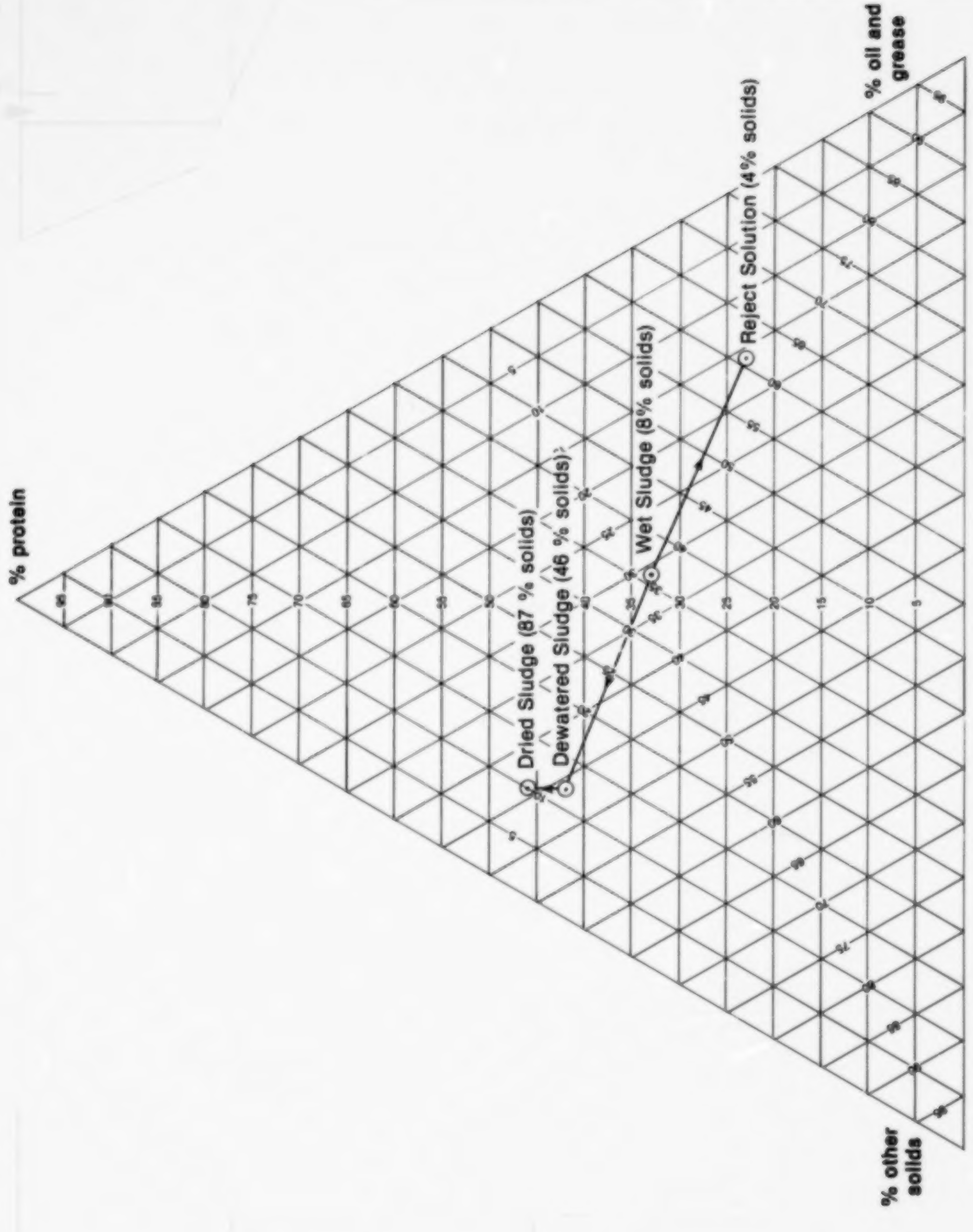

Figure 15. Solids Composition

TABLE 49. ULTIMATE FATE OF THE INCOMING WET SLUDGE

Component (1)	Incoming wet sludge, % (2)	Centrifuge reject solution, % (3)	Sludge drier vapor, % (4)	Dried sludge, % (5)
Total Solids	100	48	2	50
Protein	100	34	-4	70
Grease and oil	100	82	4	14
Other Solids	100	24	5	71
Water	100	94	5	1
Total	100	90	5	5

In order to observe the effect of centrifuge rpm on centrifuge efficiency, tests were run at various speeds between 383 and 465 rpm. Observation of the concentrations of suspended solids, total solids, oil and grease, protein, and fixed solids were made on the dewatered sludge and the reject solution. Within the rpm range tested, there was no consistent change in any of the observed quantities.

OPTIMUM pH AND LIGNOSULFONATE CONCENTRATION

Using equation 1, the optimum pH for a given temperature T and chitosin dose D can be determined as follows:

$$\frac{dF}{d(pH)} = 52-13.2\,(pH)-0.091T+0.12D=0 \qquad (16)$$

$$\frac{d^2F}{d\,(pH)^2} = -13.2 < 0 \qquad (17)$$

Because $d^2F/d\,(pH)^2 < 0$, the pH value given by equation 16 will make F a maximum. Consequently, the optimum pH is:

$$pH=3.94-0.00689T+0.00909D \qquad (18)$$

which indicates that the optimum pH increases with D. Equation 18 can be written:

$$pH+0.00689T=\alpha+\beta R \qquad (19)$$

In order to obtain the values of α and β in equation 19, it is necessary to select those days that the Alwatech Wastewater Treatment Plant performed the best. Data for the 20 best days of Table 32 are given again in Table 50. Again the ratio:

$$\frac{\text{mg/l Calcium Lignosulfonate}}{\text{mg/l COD in influent}} = R \qquad (20)$$

will be employed. Using the data in columns 1, 2, and 3 of Table 50, the constants in equation 19 were evaluated to give (correlation coefficient=0.68):

$$pH=2.47-0.00689T+3.71R \qquad (21)$$

TABLE 50. DATA FOR DETERMINATION OF OPTIMUM pH

Wastewater temperature, °F (1)	R (2)	pH (3)	COD Removal, % (4)
97	0.1273	2.75	88
94	0.0855	2.65	87
97	0.0151	1.9	87
96	0.0418	2.45	86
100	0.0594	2.45	86
102	0.0898	2.56	85
100	0.1168	2.6	85
102	0.0653	2.5	85
98	0.0545	2.6	85
98	0.1329	2.7	84
97	0.1203	2.6	84
104	0.1429	2.54	84
99	0.0468	2.6	82
100	0.1161	2.68	81
98	0.0689	2.7	81
99	0.0462	2.15	81
99	0.0653	2.6	81
103	0.0662	2.35	80
98	0.1115	2.65	80
101	0.1092	2.55	80
Mean 99	0.0841	2.53	84

where T is in °C. The value of the temperature term in equation 21 is practically constant at 0.26±0.02, so an approximation of equation 21 is:

$$pH \cong 2.21+3.71R \qquad (22)$$

Because of the expense of Calcium Lignosulfonate, it is better to minimize R even though this may decrease the optimum pH and consequently increase the quantities of H_2SO_4 and Ca $(OH)_2$ required. If one takes the average of the 10 lowest values of R in Table 50, the average R obtained is 0.053, and the corresponding average pH is 2.43, with a resulting average COD removal of 83%. For the 20 values listed in Table 50, the average flow rate through the plant varied from 15,562 to 24,800 gal/hr per flotation tank with no discernable effect on % COD removal.

% COD REMOVAL AND OTHER PLANT PERFORMANCE PARAMETERS

Table 51 lists the same 20 values of COD used in Table 50 along with the influent COD concentration and 9 other plant performance parameters. The % COD removal does not appear to be significantly influenced by the incoming COD concentration. As expected the % BOD removal and the % COD removal are essentially identical. % removal of oil and grease averages about 9% greater than % COD removal. Average phosphate and average ammonia % removals are about the same. Organic nitrogen removal is comparable to % COD removal.

Because of the chemicals added, the net change in solids concentration is insignificant. However, volatile solids removal is about the same as % COD removal. Suspended solids removal is about the same as COD removal. However, volatile suspended solids removal is about 8% higher than % COD removal.

SULFURIC ACID AND CALCIUM HYDROXIDE REQUIREMENTS

From the last page of Table 32, the average pH 3 alkalinity was 19.4 me/l. The average pH after addition of lignosulfonate and sulfuric acid was 2.56, while the plant influent pH averaged 6.97. Therefore, the change in pH was (6.97-3.00 =) 3.97 and therefore the acid requirement was (19.4 ÷ 3.97 =) 4.89 me/l per Δ pH unit. The actual pH change was (6.97-2.56 =)4.41 pH units so the total acid requirement was (4.41x4.89 =) 21.6 me/l. The average concentration of sulfuric acid used was 1,106 mg/l, so the ratio (1,106÷ 21.6 =) 51 grams per equivalent is close to the equivalent weight of sulfuric acid (49 grams per equivalent). Consequently, it appears that for this wastewater the ratio (1,106÷4.41 =) 251 mg/l H_2SO_4 per unit change in pH can be used for estimation purposes.

The Alwatech effluent alkalinity is 9.3 me/l on the average and the average effluent pH was 3.83. This time, the change in pH was (3.83-3.00)=0.83 and therefore the acid requirement was (9.3÷0.83 =) 11.2 me/l per Δ pH unit. The actual pH change was (3.83-2.56 =)1.27 pH units,

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TABLE 51. % COD REMOVAL AND OTHER PLANT PERFORMANCE PARAMETERS

mg/l COD in influent (1)	% Removal									
	COD (2)	BOD (3)	Oil and grease (4)	Phosphate (5)	NH_3-N (6)	Organic N (7)	Solids (8)	Volatile solids (9)	Suspended solids (10)	Volatile suspended solids (11)
4,400	81	82	97						92	
4,670	80	82	97						86	
4,400	85	80	91						78	
4,500	84	79	94						75	
3,750	85	85	99						88	
3,960	88	87	97						84	
4,130	84	82	98						88	
3,830	84	81	87						84	
5,100	87	88	94	65	75	81	0		85	
5,700	81	80	86	29	61	35			79	
5,660	82	82	89	88	44	93	21		84	
3,120	80	80	89				26		86	
6,800	80	81	91					73	89	90
18,600	87	88	98		61	100	13		88	88
6,300	81	80	89						81	
6,650	86	84	94		44	82	22	98	94	94
4,500	85	87							85	
7,520	86	83	95						95	
5,500	85	84	93	40	45	80	25	85	96	96
4,900	81	80	93						84	
5,700	84	83	93	56	55	79	18	85	86	92 Average

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so the total acid requirement was (1.27x11.2 =) 14.2 me/l. The average concentration of calcium hydroxide used was 560 mg/l, so the ratio (560÷14.2 =) 39 grams per equivalent is close to the equivalent weight of calcium hydroxide (37 grams per equivalent). Consequently, it appears that for this treated effluent the ratio (560÷1.27 =) 441 mg/l $Ca(OH)_2$ per unit change in pH can be used for estimation purposes.

From Table 29, an average of 64.5 pounds of $Ca(OH)_2$ was required per 1,000 gallons of sludge for sludge neutralization. Because there was an average of 26.6 gallons of sludge per 1,000 gallons of wastewater treated, this is equivalent to 1.72 lb $Ca(OH)_2$ per 1,000 gallons of wastewater (206 mg/l). Consequently, the amount of $Ca(OH)_2$ required for sludge neutralization was (206÷560 =) 37% of that required for treated effluent neutralization. Therefore, one can use a figure of (1.37x441 =) 604 mg/l $Ca(OH)_2$ per unit change in pH to estimate the total cost of both treated effluent and sludge neutralization.

MINIMUM COST pH

The costs of the chemicals used are as follows:

	¢/lb
Calcium Lignosulfonate	22.36
H_2SO_4	2.78
$Ca(OH)_2$	2.70

For the purposes of this analysis, we will assume that the influent pH is 6.97 and that the effluent pH is 3.83. We will use pH to represent the resulting pH after the addition of Calcium Lignosulfonate and H_2SO_4. Therefore, the acid requirement is:

$$(251)\ (6.97-\mathrm{pH})=\mathrm{mg/l}\ H_2SO_4 \qquad (23)$$

The base requirement is:

$$(604)(3.83-\mathrm{pH})=\mathrm{mg/l}\ Ca\ (OH)_2 \qquad (24)$$

The calcium Lignosulfonate requirement is:

$$\mathrm{mg/l\ Calcium\ Lignosulfonate}=R\ (\mathrm{mg/l\ COD\ in\ influent}) \qquad (25)$$

Equation 25 can also be written for brevity:

$$\mathrm{mg/l\ Ca\ LS}=R\ (\mathrm{mg/l\ COD}) \qquad (25)$$

From equation 22 it appears that R and pH are related. In order to gain some insight into this relationship, Table 52 was constructed using only that data from Table 32 corresponding to a COD removal of 70% or better (which corresponds to the 70% BOD removal figure in Table 26). A least squares fit of the data in columns 1 and 2 of Table 52 gave the following result (correlation coefficient=0.844):

$$R=-0.097+0.071\ \mathrm{pH} \qquad (26)$$

Equation 26 is plotted in Figure 16 along with the data in columns 1 and 2 of Table 52. The points in Figure 16 are labeled with the data in columns 3 and 4 of Table 52. Substituting equation 26 into equation 25 gives:

$$\mathrm{mg/l\ Ca\ LS}=0.071\ (\mathrm{pH}-1.37)\ (\mathrm{mg/l\ COD}) \qquad (27)$$

The cost of the 3 chemicals used can be restated as follows:

TABLE 52. R versus pH

pH (1)	Average R (2)	Average % COD removal (3)	# of points (4)
1.9±0.05	0.015	87	1
2 ±0.05	0.071	77	2
2.1±0.05			0
2.2±0.05	0.046	81	1
2.3±0.05			0
2.4±0.05	0.082	76	5
2.5±0.05	0.072	80	7
2.6±0.05	0.104	80	13
2.7±0.05	0.100	79	10
2.8±0.05	0.096	78	6
2.9±0.05	0.097	75	1
Total			46
Average		79	

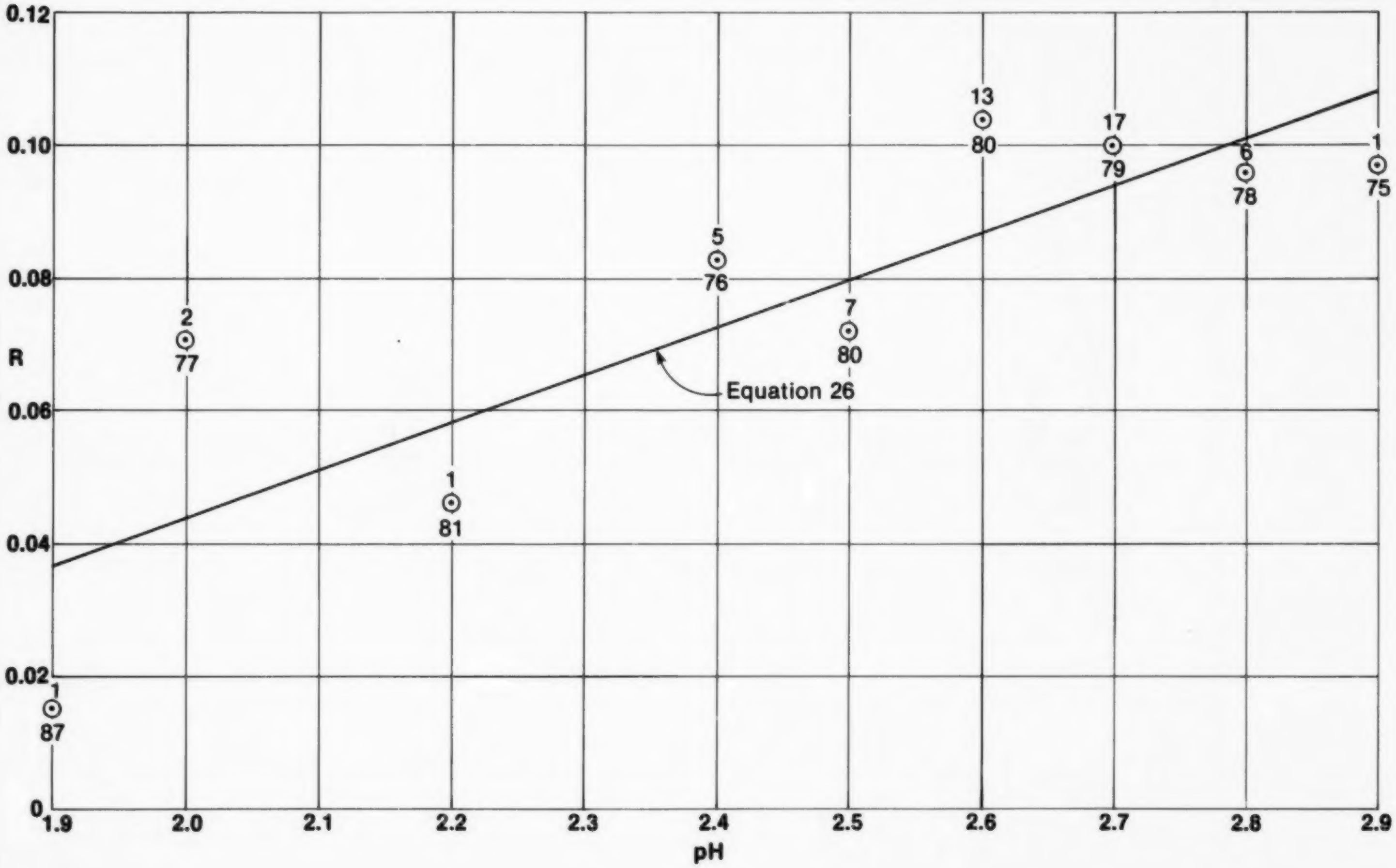

Figure 16. R versus pH

	¢ per mg
Calcium Lignosulfonate	$49.2\text{x}10^{-6}$
H_2SO_4	$6.12\text{x}10^{-6}$
$Ca\ (OH)_2$	$5.95\text{x}10^{-6}$

Therefore the total chemical cost per liter is:

$$¢/l=6.12\text{x}10^{-6}\ (mg/l\ H_2SO_4)+5.95\text{x}10^{-6}\ [mg/l\ Ca\ (OH)_2]\ + +49.2\text{x}10^{-6}\ (mg/l\ Ca\ LS) \qquad (28)$$

Equation 28 can be written in less cumbersome fashion as the total chemical cost per 10^6 liters:

$$¢/10^6 l=6.12\ (mg/l\ H_2SO_4)+5.95\ [mg/l\ Ca\ (OH)_2]\ +49.2\ (mg/l\ Ca\ LS) \qquad (29)$$

Substituting equations 23, 24, and 27 into equation 29 gives:

$$¢/10^6 l=1,536(6.97-pH)+3,594(3.83-pH)+3.49(pH-1.37)(mg/l\ COD) \qquad (30)$$

or equation 30 can be rewritten:

$$\$/10^6 l=15.4(6.97-pH)+35.9(3.83-pH)+0.0349(pH-1.37)(mg/l\ COD) \qquad (31)$$

Or in more familiar terms, equation 31 becomes:

$$\$/10^6\ gal=58.3(6.97-pH)+136(3.83-pH)+0.132(pH-1.37)(mg/l\ COD) \qquad (32)$$

In equation 32, the first term [58.3(6.97-pH)] is the H_2SO_4 cost, the second term [136(3.83-pH)] is the $Ca(OH)_2$ cost for both effluent and sludge neutralization, and the last term [0.132(pH-1.37)(mg/l COD)] is the calcium lignosulfonate cost. Comparision of the individual terms of equation 32 with the observed H_2SO_4, $Ca(OH)_2$, and Calcium Lignosulfonate costs for the last 10 weeks of operation revealed that on the average the calculated costs for both H_2SO_4 and $Ca(OH)_2$ were within 0.5% of the observed costs. On the other hand, the observed Calcium Lignosulfonate costs were only about 85% of the calculated Calcium Lignosulfonate costs. Therefore, it appears that this term should be reduced on the average about 15%, so that Equation 32 should be corrected to:

$$\$/10^6\ gal=58.3(6.97-pH)+136(3.83-pH)+0.112(pH-1.37)(mg/l\ COD) \qquad (33)$$

The observed average total cost of these 3 chemicals for the last 10 weeks was $1,080 per million gallons and the average calculated cost using equation 33 was the same. Of this total cost, $Ca(OH)_2$ represented 16%, H_2SO_4 represented 23%, and the Calcium Lignosulfonate represented the remaining 61%. There appears tc be no relationship between the influent COD concentration and the pH used.

From Figure 16 it is clear that satisfactory COD removals (roughly 80%) were observed at pH values ranging all the way from 1.9 to 2.9 which is quite close to the optimum pH range of 2 to 3 reported in Table 15.

For other plants with different incoming pH values (pH_I) and different effluent pH values (pH_E), equation 33 can be generalized to:

$$\$/10^6\ gal=58.3(pH_I-pH)+136(pH_E-pH)+0.112(pH-1.37)(mg/l\ COD) \qquad (34)$$

From equation 33 it is clear that the chemical costs depend on the pH used and the influent COD concentration. In order to examine this more easily, equation 33 can be simplified to:

$$\$/10^6\ gal=927-194\ pH+(0.112\ pH-0.153)(mg/l\ COD) \qquad (35)$$

Equation 35 is plotted in Figure 17. It appears that for COD

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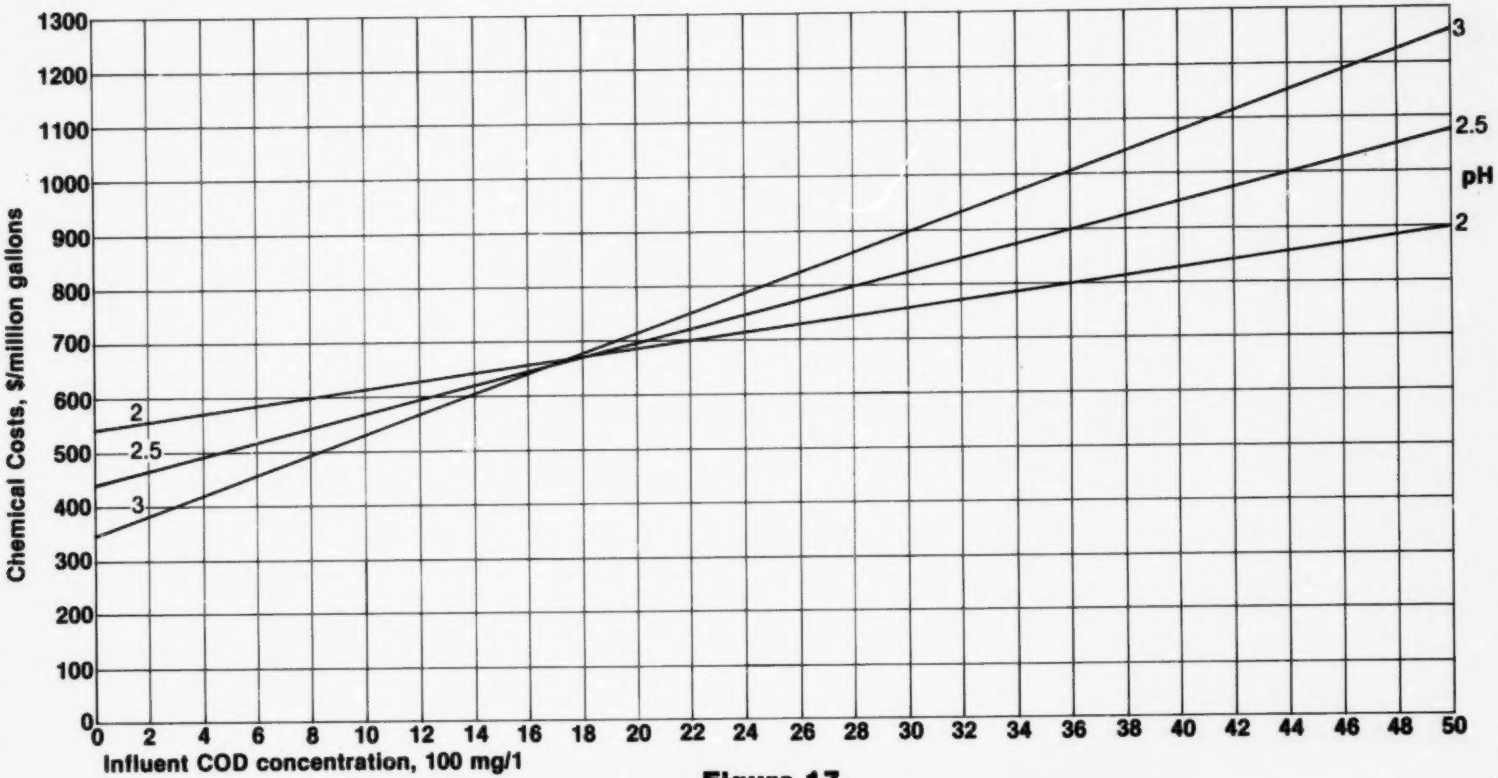

Figure 17.
Chemical Cost as a function of pH used and influent COD concentration (Equation 35)

concentrations below about 1,800 mg/l, it would be less expensive to use higher pH values just below 3, while above this concentration it appears that the lower pH values just above 2 would be less expensive. At this plant only one COD value fell below 1,800 mg/l (1,680 mg/l).

Using the average values observed during the course of the project, namely pH=2.56 and influent COD concentration=4,607 mg/l, Equation 35 gives a cost of $1,050 per million gallons, a figure that is within 3% of the average observed for the last 10 weeks.

It is worthwhile examining the additional cost that would have resulted had the effluent pH been raised to pH 7. Using Equation 34, and the fact that (100÷1.37 =) 73% of the $Ca(OH)_2$ used was for effluent neutralization, the additional cost is calculated to be $315 per million gallons.

MONTHLY AVERAGE EFFLUENT CONCENTRATIONS

At the specific request of the project officer, monthly average effluent concentrations were calculated for 6 water quality parameters, and these results are given in Table 53 for a 6 month period. The large variability exhibited is entirely expected because the effluent concentrations are determined by 2 relatively variable quantities: influent concentration and % removal. With the exception of phosphate and ammonia N, the coefficients of variation of the effluent concentrations are greater than the coefficients of variation of either the influent concentration or the % removal. In any event, it can be seen that calculation of an average effluent concentration from the average influent concentration and average % removal (on the last page of Table 32) gives values well within the range determined directly from the effluent concentrations. In general, a coefficient of variation greater than 1 indicates a frequency distribution that is not a normal frequency distribution (such as a geometric or log normal frequency distribution). In a log normal frequency distribution, the logs of the values have a normal frequency distribution.

For example, the grease and oil effluent concentrations are plotted for September, 1978, in Figure 18. Consequently, it is clear that the mean of the log normal frequency distribution, 40 mg/l, is more representative of the effluent concentration than the arithmetic mean of 86 mg/l. In addition the geometric standard deviation of 4.8 is more representative of the variation than the arithmetic standard deviation of 93 mg/l.

Another example, the effluent suspended solids concentrations for September, 1978, is plotted in Figure 19. Again it is apparent that the geometric mean of 309 mg/l is more representative of the suspended solids effluent concentration than the arithmetic mean of 427 mg/l. Also, once again, the geometric standard deviation of 2.2 is more representative of the effluent concentration variation than the

TABLE 53. MONTHLY AVERAGE EFFLUENT CONCENTRATIONS

Month	Year	Measure	5-Day, 20°C BOD, mg/l	Grease and Oil, mg/l	Phos-phate, mg/lP	NH_3-N, mg/l N	Organic N, mg/l N	Total Suspended Solids, mg/l
August	1978	Average	623	30	-	-	-	290
		Standard deviation	32	5	-	-	-	102
		Coefficient of variation	0.05	0.17	-	-	-	0.35
September	1978	Average	1,264	86	-	39	43	427
		Standard deviation	757	93	-	8	7	448
		Coefficient of variation	0.60	1.08	-	0.21	0.16	1.05
October	1978	Average	514	51	-	46	9	335
		Standard deviation	141	110	-	-	-	152
		Coefficient of variation	0.27	2.16	-	-	-	0.45
November	1978	Average	700	99	18	38	43	371
		Standard deviation	243	59	9	15	22	83
		Coefficient of variation	0.35	0.60	0.50	0.39	0.51	0.22
December	1978	Average	822	207	2	50	69	574
		Standard deviation	312	232	1	10	26	325
		Coefficient of variation	0.38	1.12	0.50	0.20	0.38	0.57
January	1979	Average	1,351	105	-	-	-	1,301
		Standard deviation	412	92	-	-	-	976
		Coefficient of variation	0.30	0.88	-	-	-	0.75
August, 1978 through January, 1979		Average	806	97	15	41	46	560
		Standard deviation	413	132	11	13	24	569
		Coefficient of variation	0.51	1.36	0.73	0.32	0.52	1.02
Calculated from last page of Table 32		Average	854	103	9	48	47	542

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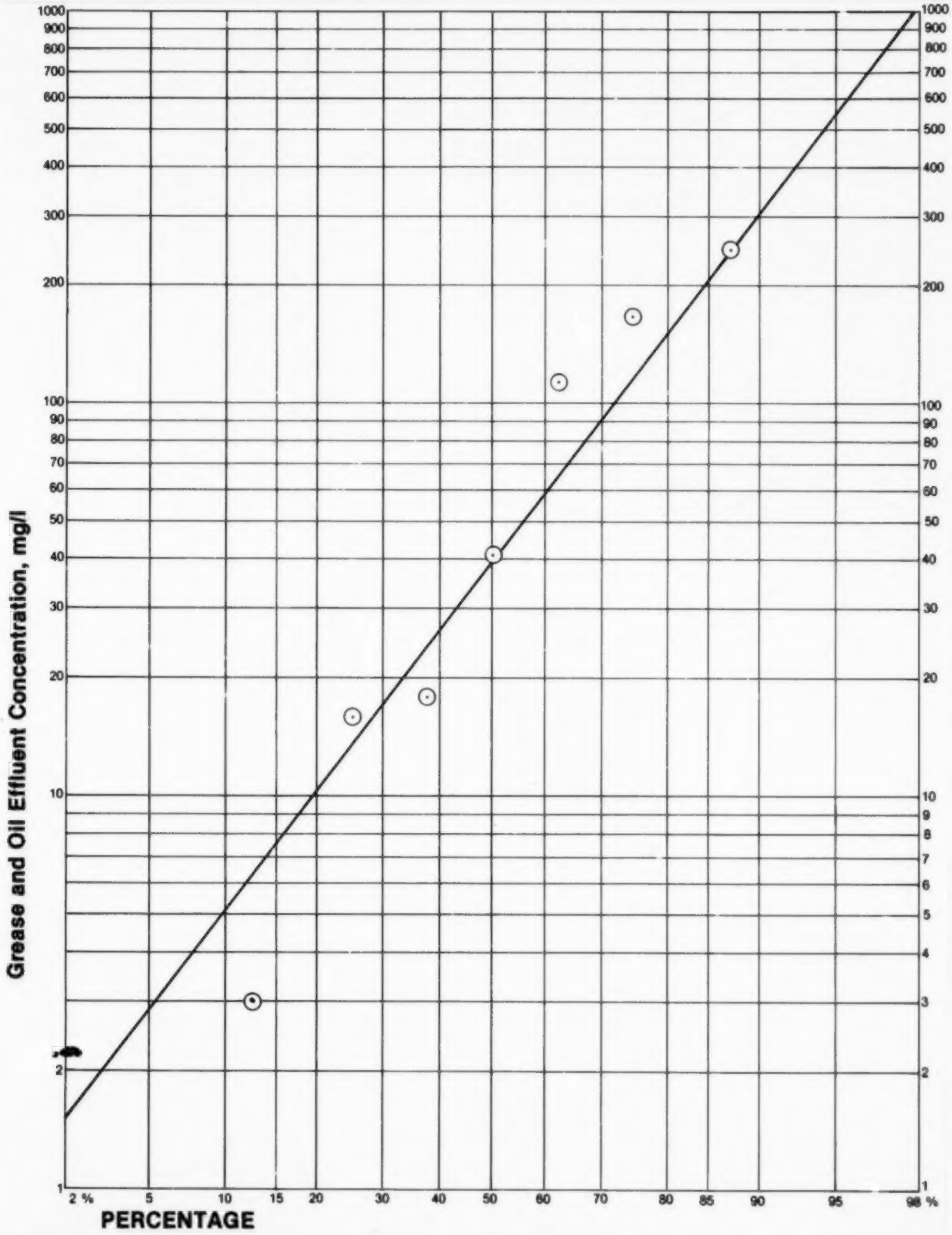

Figure 18.
Frequency Distribution of September, 1978,
Grease & Oil Effluent Concentrations

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EPA 287 (Cin.)
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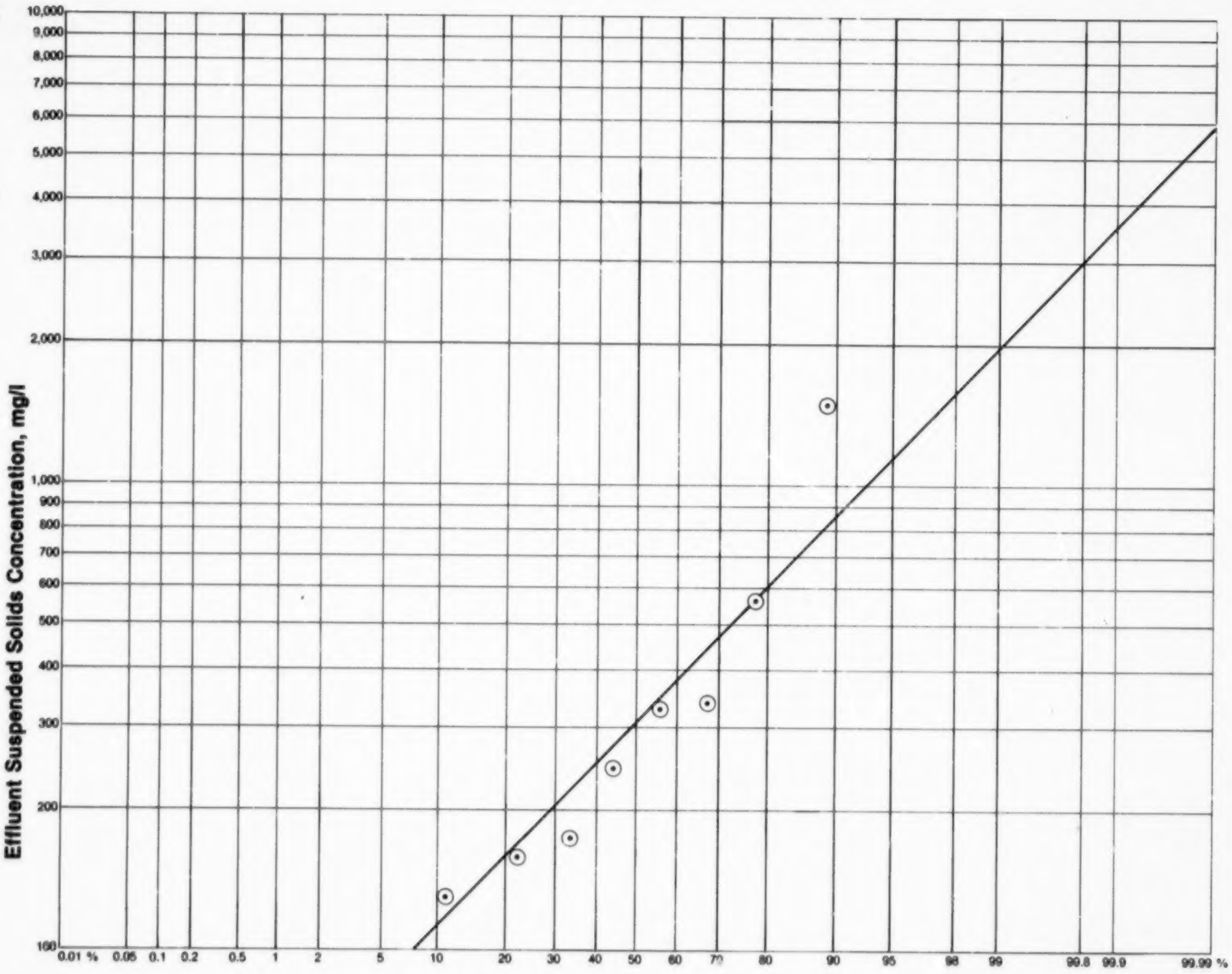

Figure 19.
Effluent Suspended Solids Concentration
Frequency Distribution for September, 1978

arithmetic standard deviation of 448 mg/l.

From these 2 examples it appears that where the effluent concentration coefficient of variation is high, the frequency distribution may be log normal. Also, it appears that usually the geometric mean may be more representative in this case, and that it tends to be less than the arithmetic mean.

SECTION 8

PROTEIN RECOVERY ECONOMICS

From Table 40, the average total solids recovered was 5 pounds per 1,000 pounds of live weight. From the last page of Table 38, the dried solids averaged 38% protein, so 1.9 pounds of protein were recovered per 1,000 pounds of live weight. For the period July 5, 1978, through February 23, 1979, the average live weight of cattle killed was 1,040 pounds per head. On a weekly average basis this figure varied from 1,013 to 1,062 pounds per head, so the maximum observed departure from the average was less than 3% of the average. Consequently, about 2 pounds of protein was recovered per head.

From Table 30, the average quantity of wastewater treated in the Alwatech plant was 276 gallons per head. The average chemical cost of treating this wastewater was $1,080 per million gallons, or 30¢ per head. Therefore, if the recovered protein can be sold for 15¢ per pound, then this would be sufficient to cover the chemical costs.

TOTAL OPERATING COSTS

The Alwatech plant operates 16 hours per day and requires 3 men per 16 hour day. This plant is operated 6 days per week (but with only 2 men on Saturday) if the slaughterhouse is operated 5 days per week. Consequently, total time required is 17 man-days per week. At a cost of $7.50 per man-hour, this represents a cost of $1,020 per week.

For the last 10 weeks, the plant processed an average of 8,752 head of cattle per week, and the Alwatech plant treated an average of 2,448,000 gallons of wastewater per week. Consequently, labor costs averaged 12¢ per head or $417 per million gallons treated.

From Section 6, other costs are as follows (labor for maintenance is included in the previous figures). Repairs averaged $92 per week or 1¢ per head or $38 per million gallons. Energy costs in 1979 averaged $146 per million gallons or about 4¢ per head. From Section 7, average chemical costs of $1,080 per million gallons were composed of the following:

chemical	$\$/10^6$ gal
$Ca(OH)_2$	173
H_2SO_4	248
Calcium Lignosulfonate	659
Total	1,080

Total operating costs are summarized in Table 54. From this table it is clear that by far the largest single component of the total operating costs is the cost of Calcium Lignosulfonate (39% of total operating costs). From Section 6, it is clear that the cost of Calcium Lignosulfonate could be reduced to about 60% of the figures given in Table 54 without affecting plant performance (% COD removal, etc.) or protein recovery. If this were done, the cost of Calcium Lignosulfonate would be reduced to $395 per million gallons or about 11¢ per head. This would reduce total operating costs to 40¢ per head (a 15% reduction in total operating costs). Calcium Lignosulfonate would then constitute only about 28% of the total operating costs, but it would still remain the second largest single component of total operating costs (labor would then constitute 30% of total operating costs).

From the data obtained during the course of this project, it appears that even further reductions in the quantity of Calcium Lignosulfonate may be possible without an adverse effect on plant performance (% COD removal, etc.) or protein recovery. Using the figures in Table 54, it is clear that the protein recovered would have to sell for 23.5¢ per pound in order to compensate for all operating costs, but from the foregoing discussion, it is clear that this price could be reduced to 20¢ per pound if the recommended 40% reduction in Calcium Lignosulfonate concentration was used.

In order to estimate the effect of using lower concentrations of Calcium Lignosulfonate on plant performance (COD removal, etc.) and protein recovery, the 77 values of R used were grouped in groups of 10; the 10 lowest values of R used were grouped together, the 10 highest values of R used were grouped together, etc. These results are given in Table 55. The data in columns 2 and 3 of this table were subjected to a least squares analysis with the following results (correlation coefficient=-0.75):

$$\%\ \text{COD removal} = 81.5e^{-1.46R} \tag{36}$$

Equation 36 is plotted in Figure 20 along with the data from columns 2 and 3 of Table 55. It is particularly noteworthy that the lowest 20 values of R gave the highest % COD removal, while the highest 10 values of R gave the lowest % COD removal. The 20 lowest values of R are given in Table 56 in column 1 along with their corresponding % COD removal values in column 2. Columns 3 and 4 are the first 3 term moving averages, columns 5 and 6 are the second 3 term moving averages, and columns 7 and 8 are the third 3 term moving averages.

TABLE 54. TOTAL OPERATING COSTS

Operating cost component (1)	¢ per head (2)	\$ per 10^6 gal treated (3)	% of total operating costs (4)
Labor	12	417	25
Repairs of Alwatech plant	1	38	2
Energy (1979)	4	146	9
$Ca(OH)_2$	5	173	10
H_2SO_4	7	248	15
Calcium Lignosulfonate	18	659	39
Total operating costs	47	1,681	100

TABLE 55. EFFECT OF R ON % COD REMOVAL

Number of Values Averaged (1)	Average R Value (2)	Average % COD Removal (3)
10	0.037	77
10	0.065	76
10	0.075	67
10	0.088	69
7	0.095	72
10	0.115	75
10	0.129	69
10	0.177	60
Total 77		

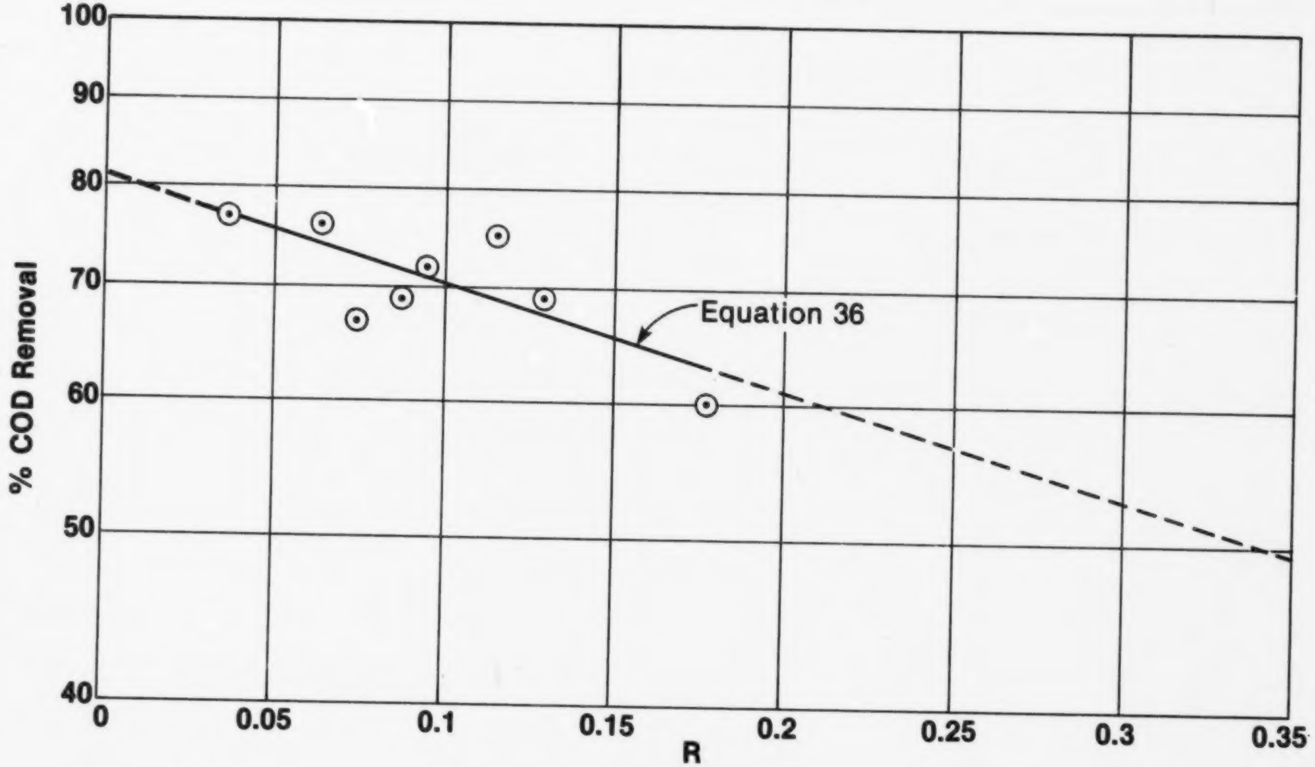

Figure 20.
Effect of R on % COD Removal

TABLE 56. THE 20 LOWEST VALUES OF R USED

R	% COD Removal	First 3 Term moving average		Second 3 Term moving average		Third 3 Term moving average	
		R	% COD Removal	R	% COD Removal	R	% COD Removal
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
0	65						
0.015	87	0.014	73				
0.028	67	0.027	76	0.026	75		
0.039	75	0.036	76	0.035	77	0.034	77
0.042	86	0.042	78	0.041	78	0.040	78
0.044	73	0.044	80	0.044	79	0.044	79
0.046	81	0.046	79	0.046	79	0.046	79
0.047	82	0.048	78	0.048	79	0.048	79
0.052	72	0.051	80	0.051	80	0.051	79
0.055	85	0.055	81	0.055	79	0.055	79
0.059	86	0.059	77	0.058	77	0.058	76
0.062	60	0.061	74	0.061	72	0.061	73
0.063	77	0.063	66	0.063	71	0.063	72
0.063	60	0.064	74	0.064	72	0.064	73
0.065	85	0.064	75	0.064	77	0.064	76
0.056	81	0.065	82	0.065	79	0.065	79
0.066	80	0.066	79	0.066	80	0.066	79
0.067	76	0.067	79	0.067	79		
0.069	81	0.068	78				
0.069	78						

The first and last R values in columns 1,3, and 5 along with all the R values in column 7 are plotted in Figure 21 (the points are labeled with the corresponding moving average; 2=second 3 term moving average, etc.). Clearly, the lowest value of R giving the highest % COD removal is $R=0.05\pm0.005$ at which an average COD removal of 79% can be expected. From equation 26 the corresonding pH is 2.075 ± 0.075. Substituting this pH value into equation 35 gives a total chemical cost of:

$$\$/10^6 \text{ gal}=524+0.079(\text{mg/l COD}). \qquad (37)$$

Figure 21 indicates that values of $R<0.05$ do not give greatly reduced % COD removals, but it must be remembered that the points plotted are based on fewer and fewer observations as $R\rightarrow0$, and the point at $R=0$ is based on only 1 observation. Nevertheless it is believed that because of the cost of Calcium Lignosulfonate, it would be worthwhile to experiment with values of $R<0.05$, although based on the existing data, one could not recommend a value of $R<0.05$ at this time.

If one assumes that the value of $R=0$ is correct it may appear relatively expensive to increase operating costs from 29¢ per head to 40¢ per head merely to increase COD removal from 65% to 79%. However, the % COD remaining in the effluent at $R=0$ is 35% and the % COD remaining in the effluent at $R=0.05$ is 21%, so the amount of COD remaining in the effluent is reduced 40% by an increase of 38% in operating costs.

CAPITAL COSTS

The following equation is based on an analytical derivation and has been verified with observed data:

$$\text{Capital cost} = (\text{constant})\ (\text{capacity})^n, \text{ where} \qquad (38)$$

Capital cost is in $,
Capacity is in gallons per day,
and n has a theoretical value of 2/3.

Alwatech furnished the following cost estimate for 3 different capacity plants. These capital investment estimates include the chemical treatment system, sludge dewatering system, erection materials, and erection:

Nominal plant capacity, gallons per day (16 hours per day)	Capital Cost, $
800,000	807,000
1,200,000	1,044,000
1,600,000	1,333,500

A least squares fit of the foregoing data with equation 10-3 gave the following results:

$$\text{Capital cost,\$}=45.7\ (\text{capacity,gpd})^{0.719} \qquad (39)$$

Equation 39 has a correlation coefficient of 0.997. As mentioned previously, the Alwatceh plant installed at the Sterling Colorado

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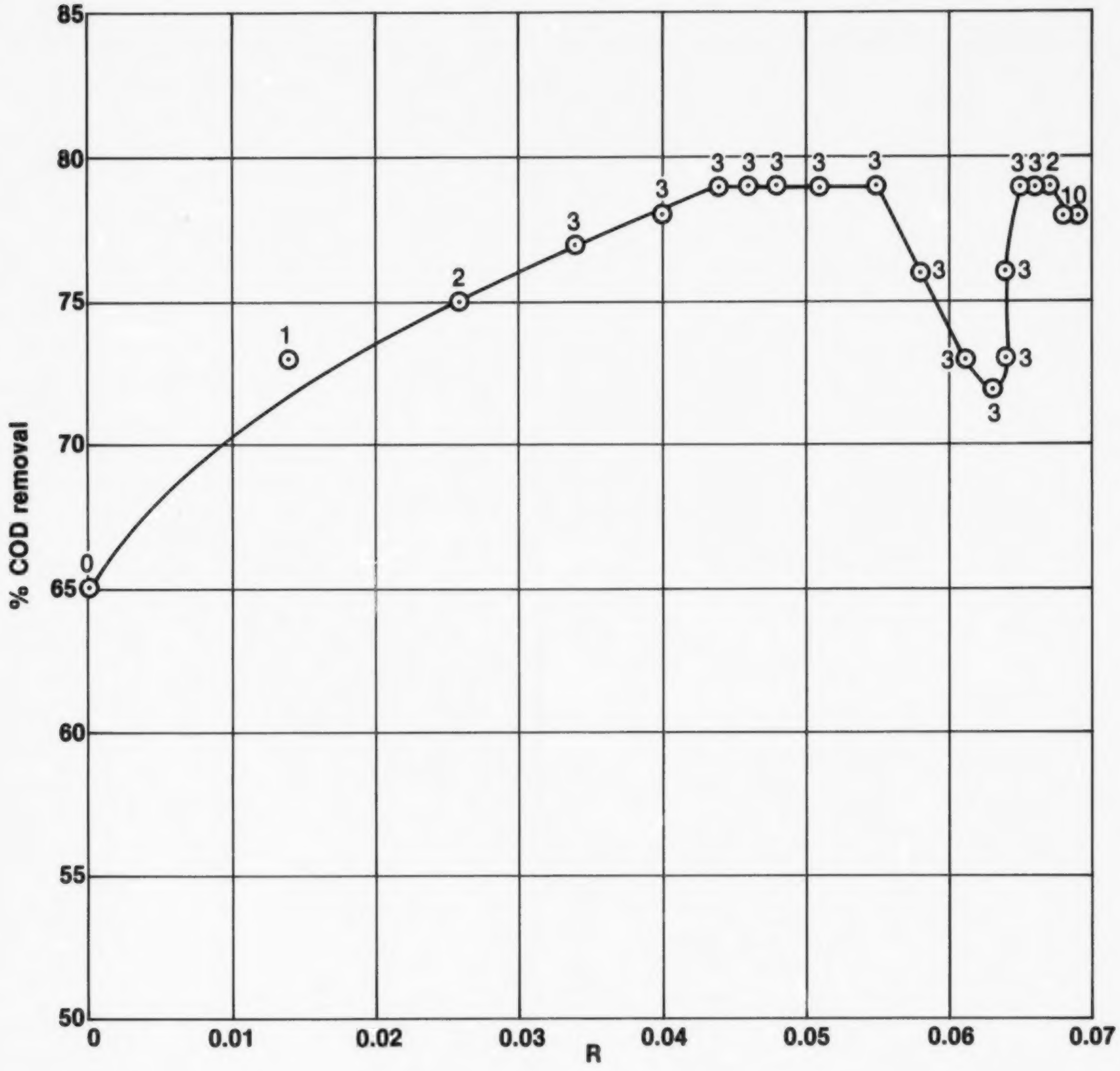

Figure 21. Optimum R

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Beef Company was designed to treat up to 800,000 gallons per day. The actual cost of this latter plant was \$910,644 which represents an additional cost of \$103,644 for laboratory equipment, plant heating equipment, laboratory air conditioning, control room air conditioning, and $Ca(OH)_2$ and H_2SO_4 storage. In addition, the building (including a service tunnel to the packing plant) was \$392,288, so that the total cost was actually \$1,302,932, or 1.61 times that given by equation 39. Therefore a more realistic equation is

$$c = 73.6\ Q^{0.719} \tag{40}$$

where

c = capital cost, \$

Q= capacity (16 hours/day), gallons per day.

Therefore the annual costs are

$$\$\text{per year} = c(p+i+t^{-1}+I) \tag{41}$$

where

p= property taxation rate, decimal per year

i= interest rate, decimal per year

t= life of the system, years

I= annual cost of insurance,decimal per year.

The Sterling Colorado Beef Company uses the following values for these 4 parameters:

p= 0.02798 per year

i= 0.1275 per year

t= 20 years

I= 0.00509 per year (based on 95% replacement). Using these figures, equation 41 becomes

$$\$\text{per year} = 0.211c \tag{42}$$

or the capital costs are \$274,919 per year.

If the plant is operated 16 hours per day, 5 days per week, 4 million gallons will be treated per week or 209 million gallons per year, so that the capital cost for an 800,000 gpd plant is \$1,315 per million gallons. Using equations 40 and 42, the capital costs for a 1,600,000 gpd plant would be \$1,073 per million gallons.

SECTION 9

COMPARISON OF THE ALWATECH PROCESS RESULTS WITH OTHER PROTEIN RECOVERY PROCESSES

From Section 4, there are at least 5 potential protein recovery processes that might be applied to this wastewater:

1. Production of Functional Protein by Enzymatic Digestion
2. Protein Recovery by Ion Exchange
3. Protein Recovery by Reverse Osmosis
4. Protein Recovery Using Chitosin
5. Protein Recovery Using Lignosulfonate

However, there is no published data available for the first 3 processes listed above that would permit a reasonable comparison with the last process listed above. Consequently, the discussion in this section is restricted to comparison of the last 2 processes listed above.

From Table 12, it is clear that in order to obtain the % COD removals that are possible using Lignosulfonate, about 40,000 mg/l of activated carbon in addition to Chitosin would be required. In fact, the % COD removal with no activated carbon (using Chitosin only) is only 37%. Yet the costs in Table 13 do not include the cost of labor and activated carbon. From Table 13, total operating expenses (excluding capital recovery) are $7,590 per million gallons for treating a waste with 12,400 mg/l COD and removing 37% of the influent COD using Chitosin. Using equation 35 (pH=2) and the pertinent data from Table 54, the corresponding costs using Calcium Lignosulfonate would be only $1,565 per million gallons, and the expected % COD removal would be considerably greater. Clearly the lignosulfonate process gives substantially better results for a fraction of the cost.

Even adding capital costs of $1,315 per million gallons, the total costs using Calcium Lignosulfonate would be $2,880 per million gallons.

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SECTION 10

MATERIAL BALANCES OF POLLUTANTS AROUND THE ALWATECH PROCESS

The requirement for this section is, "Make material balances of pollutants around the LSA (sic) process over at least two 5-day periods of typical operation including measurement of settled solid discharged from the bottom of the air flotation tank." Measurements of the settled solids discharged from the bottoms of the air flotation tanks are reported in Table 37. Consequently, this section will concentrate on material balances of pollutants around the lignosulfonate process over two 5-day periods of typical operation. These two 5-day periods were observed October 17-30, 1978. The pollutants measured were COD, BOD, grease and oil, and total suspended solids. Because COD is a better measurement of the quantities measured by BOD, and because the behavior of COD and BOD in this wastewater is essentially identical, redundant material balances using BOD will be omitted for the sake of brevity.

The data required for these material balances are shown in Table 57. The data in columns 1-8 came from Table 32. Additional information required for these material balances is given in Table 58. From Figure 14 it is clear that 90.361% of the wet sludge becomes centrifuge reject solution and 9.675% becomes dewatered sludge. The various liquid quantities are shown in Table 59 . The average flow rate is from column 2 of Table 57 and the average sludge production rates are from Table 58.

In order to obtain lb/hr of the various pollutants, the flow rate in gal/hr times the concentration in mg/l divided by 120,000 gives lb/hr.

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TABLE 57. DATA REQUIRED FOR MATERIAL BALANCES (OCTOBER, 1978)

Day (1)	Flow rate, gal/hr (2)	COD, mg/1		Grease and oil, mg/1		Suspended solids, mg/1		Centrifuge Reject Solution mg/1			Day (1)
		influent (3)	effluent (4)	influent (5)	effluent (6)	influent (7)	effluent (8)	COD (9)	Grease and oil (10)	Suspended solids (11)	
17	48,000	4,400	660	530	48	2,000	440	61,000	9,600	21,000	17
18	40,000	4,200	882	440	35	1,200	576	65,000	650	22,000	18
19	31,124	4,500	720	510	31	2,320	580	61,000	20,500	34,400	19
20	45,400	3,750	563	115	1	1,540	185	47,000	6,900	25,600	20
23	46,400	2,950	797	330	10	1,320	330	40,800	2,800	18,600	23
Ave.	42,185	3,960	724	385	25	1,676	442	54,960	8,090	24,320	Ave.
24	43,400	3,300	693	425	34	1,560	296	30,800	3,100	13,600	24
25	42,400	3,960	475	510	15	2,200	352	42,300	3,500	17,100	25
26	45,600	4,130	661	410	8	1,700	204	41,100	1,400	18,000	26
27	45,600	3,830	613	180	23	1,880	301	62,000	4,300	20,000	27
30	46,000	3,480	800	110	11	1,760	194	--	--	--	30
Ave.	44,600	3,740	648	327	18	1,820	269	44,050	3,075	17,175	Ave.

TABLE 58. MATERIAL BALANCE SLUDGE PRODUCTION

October, 1978, day	Gallons of Sludge produced per 1,000 gallons of wastewater treated
17	10.97
18	26.95
19	29.20
20	30.42
23	23.32
Average	24.17
24	29.70
25	32.62
26	33.79
27	29.52
30	28.39
Average	30.80

COD

The COD Material Balance is given in Table 60. From Table 25, it is clear that during these 10 days, the centrifuge reject solution was hauled to landfill whereas most of the rest of the time it was pumped back into the plant influent. Therefore, the incoming COD would be increased 32%.

TABLE 59. MATERIAL BALANCE LIQUID QUANTITIES

	October 17-23, 1978	October 24-30, 1978
average influent flow rate, gal/hr	42,185	44,600
gal sludge/10^3 gal wastewater	24.2	30.8
gal sludge per hour (average)	1,021	1,374
average effluent flow rate,gal/hr	41,164	43,226
gal centrifuge reject solution per hr	923	1,242
gal dewatered sludge per hour	98	132

TABLE 60. COD MATERIAL BALANCE (lb/hr)

	October, 1978		Average
	17-23	24-30	
Influent COD	1,392	1,390	1,391
Effluent COD	248	233	240
COD Removed	1,144	1,157	1,151
COD in Centrifuge Reject Solution	423	456	440
COD in Dewatered Sludge	721	701	711

SUSPENDED SOLIDS

The Suspended Solids material balance is given in Table 61.

TABLE 61. SUSPENDED SOLIDS MATERIAL BALANCE (lb/hr)

	October, 1978		Average
	17-23	24-30	
Influent Suspended Solids	589	676	633
Effluent Suspended Solids	145	97	121
Suspended Solids Removal	444	579	512
Suspended Solids in Reject Solution	187	178	183
Suspended Solids in Dewatered Sludge	257	401	329

Again, pumping the centrifuge reject solution back into the plant influent would increase the influent suspended solids 29%.

GREASE AND OIL

The Grease and Oil Material Balance is given in Table 62. This time the grease and oil in the dewatered sludge is calculated using the quantities in Figure 14.

TABLE 62. GREASE AND OIL MATERIAL BALANCE

Pounds per hour	October, 1978		Average
	17-23	24-30	
Influent Grease and Oil	135	122	129
Effluent Grease and Oil	9	6	8
Grease and Oil Removed	126	116	121
Grease and Oil in Reject Solution	62	32	47
Grease and Oil in Dewatered Sludge	46	62	54
Error in Material Balance	18	22	20

The grease and oil concentration in the dewatered sludge is 5.63%. From these calculations it appears that the overall error in the material balances averages 16% which can be attributed to errors in laboratory analyses, etc. Once again recirculation of the centrifuge reject solution back to the plant influent increases the influent grease and oil by at least 36% and possibly as much as 52%.

% REMOVAL OF COD, SUSPENDED SOLIDS, AND GREASE AND OIL

From Tables 60,61, and 62,the % removals of COD, suspended solids, and grease and oil are:

	% removal
COD	83
Suspended solids	81
Grease and Oil	94

However, the foregoing % removal figures are based on separate disposal of the centrifuge reject solution.

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SECTION 13

APPENDIX

WASTEWATER AND SLUDGE EXAMINATION TECHNIQUES USED

All of the wastewater and sludge examination techniques used were those described in reference 51. Table 63 lists the parameters measured, their units, and also lists the parts (and letters where approriate) and pages of reference 51 that apply. Inaddition, where time and/or temperature is significant, these are also listed in Table 63. In general, where concentrations are in mg/l, these parameters refer to a liquid whereas where concentrations are expressed as %, the parameter refers to a sludge.

Alkalinity to pH3 is used because protein precipitation by LS is best when $2 \leq pH \leq 3$.

The relationship of the various solids states are given in Table 64.

TABLE 63. WASTEWATER AND SLUDGE EXAMINATION TECHNIQUES USED

#	Parameter, units, and comments	Reference 51				
		Part	*	Pages	hr	°C
1	Conductivity, μmhos/cm	205		71-75		25
2	Total residue dried at 103-105°C, mg/l	208	A	91-92	1	104
3	Total filtrable residue dried at 180°C mg/l (dissolved solids) = #2-#4	208	B	92-93	1	180
4	Total nonfiltrable residue dried at 103-105°C (total suspended matter), mg/l	208	D	94	1	104
5	Total volatile residue at 550°C, mg/l	208	E	95	1/3	550
7	Settleable matter, ml/l	208	F	95-96	1	
9	Volatile residue, mg/l	208	G	96-98	1/2	103
11	% Total residue (% solids)	208	G	96-98	1	103
12	% Volatile residue = 100 - % fixed residue (#13)	208	G	96-98		
13	% fixed residue	208	G	96-98	1	550
16	Temperature, °C	212		125		
17	The acidity to pH7, mg/l $CaCO_3$	402		273-277		25
18	The alkalinity to pH3, mg/l$CaCO_3$	403		278-280		
19	Chloride, mg/l	408	C	302,306-309		
20	Nitrogen (ammonia), mg/l ammonia N x 1.216 = mg/l NH_3, mg/l ammonia N x 1.288 = mg/l NH_4 (used specific ion activity electrode)	418		407-410		
23	Nitrogen (organic), mg/l organic N	421		437-440		
24	Kjeldahl nitrogen, mg/lN = #23 + #20					
26	pH, dimensionless	424		460-465		25
27	Phosphate, mg/l P (total)	425	A C D	466-472 474-478		
28	mg/l grease or oil	502	C	518-519		70
29	grease and oil as % dry solids	502	D	519-520		70

TABLE 63. WASTEWATER AND SLUDGE EXAMINATION TECHNIQUES USED (Continued)

#	Parameter, units, and comments	Reference 61				
		Part	*	Pages	hr	°C
30	Oxygen Demand (Biochemical), mg/l 5-day, 20°C BOD	507		543-550	120	20
31	Oxygen Demand (Chemical), mg/lCOD	508		550-554		
32	(Total) coliform colonies per 100 ml	909	B	928-937	21	35
33	Fecal coliforms per 100 ml	909	D	937-942	24	44.5
34	Fecal streptococci per 100 ml	910	B	944-945	48	35

* Letter

TABLE 64. SOLIDS STATES RELATIONSHIPS*

State of Solids	Organic	Total
Suspended	# 9	# 4
Dissolved	# 5- #9	# 3= #2- #4
Total	# 5	2

* Numbers in this table refer to the numbers (#) in the extreme left hand column of Table 63.

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

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16. ABSTRACT

The wastewater from a beef packing plant contained 4,600 mg/l COD and 2,500 mg/l of suspended solids. A physiochemical wastewater treatment process that recovers protein removed 80% of the oxygen demand and suspended solids, and 94% of the fat, oil, and grease. Total cost was $3 per 1,000 gallons (44% capital costs). About 2 pounds of protein were recovered per head. A price of 42¢ per pound of protein would pay all costs. The discharge of BOD was reduced to less than 3 pounds per head. For every pound of BOD entering the wastewater treatment plant, 0.77 pounds of product was recovered with a composition of 38% protein, 11% grease and oil, 27% inorganic solids, and 24% other solids (dry weight basis). This wastewater treatment process can be used as a pretreatment process for beef packing effluent prior to discharge to a conventional sewage treatment plant. A literature survey covering 7 different beef packing wastewater treatment processes was developed from 78 papers and reports. The cost figures given above were observed in a full scale plant and should not change significantly with different size wastewater treatment plants.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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